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General and Applied Entomology

Second Edition

B. Vasantharaj David
and
T. N. Ananthakrishnan
Consultants

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San Juan Santiago Singapore Sydney Tokyo Toronto

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ISBN 0-07-043435-2

Published by the Tata McGraw-Hill Publishing Company Limited,
7 West Patel Nagar, New Delhi 110 008, typeset in Times at Script Makers,
19, A1-B, DDA Market, Pashchim Vihar, New Delhi 110 063 and
printed at SDR Printers, A-128, West Jyoti Nagar, Loni Road,
Shahdara, Delhi 110 094

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General and Applied Entomology

Second Edition

To

Late Prof. Karunakaran K. Nayar

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Preface to the Second Edition

It is a little more than 25 years since this book was first published. The phenomenal growth of entomology during these years and the diversity of approaches adopted, have made this science truly an integrated one. The increased involvement of interdisciplinary trends as well as the replacement of outmoded pest control methods by newer ones have necessitated a revision of the first edition.

We frequently discussed the on-going changes in the approach to entomological studies and have made an effort to include as much new information as possible, to present a holistic picture of the subject. As stated in the first edition, this revised edition provides adequate information to postgraduate students in basic and applied entomology and also to students desirous of embarking on research.

With the factors controlling gene expression being better understood, there is an increased interest in crop transformations resulting from transgenics. Therefore, we have emphasized interdisciplinary interactions. The oft repeated slogan IPM or Integrated Pest Management, a concept involving the optimum combination of control methods to reduce pest population to below a threshold level, has also been discussed. Such an approach, which calls for an integration of crop production methods, i.e., a combination of agronomic, genetic, chemical and biological methods in the crop production system, has been outlined. The increased relevance of biopesticides containing plant-derived products—new molecules which have replaced earlier insecticides, fungicides and herbicides—and the increasing role of biological control of host plant resistance, have been included to make this edition as informative as possible. Lastly, the role of biodiversity in the effective functioning of ecosystems has also been discussed.

When speaking of biodiversity, one has to emphasise the role of insect taxonomy, where retaining the importance of insects of pestological value has led to the revision of existing terminologies of species, besides the addition of several new taxa. We have taken due care to discuss every aspect of insect science and industrial entomology to make this edition as comprehensive as possible.

This book is dedicated to the memory of the late Dr. K.K. Nayar, the father of insect neuroendocrinology in this country with a sense of admiration for his multiple achievements. His earlier collaboration with us has made the initiation of this edition possible.

We take this opportunity to thank Dr. V.V. Ramamurthy, Division of Entomology, Indian Agricultural Research Institute, New Delhi for providing the present valid names for many species included in the volume.

B. Vasantharaj David
T.N. Ananthakrishnan

Preface to the First Edition

The increasing emphasis on interdisciplinary approach to the study of animal life has also extended to the field of entomology and the contents of the book reveal to some degree this impact of bio-chemistry, physiology and pestology on the biology of insects. The aim in writing up this volume has therefore been to present to Indian students of entomology, an account of this modern approach. A number of very good textbooks on entomology have recently been published, but our effort is aimed at bringing out a physio-ecological book presenting the principles and practice of insect pestology. Taxonomy, which though of the classical type, remains here largely illustrative of insects of pestological value and an attempt has been made to introduce details of the biology and control of Indian and, to a limited extent, Asian insects, in this section. The essential principles of toxicology dealing with the characteristics and classification of insecticides, along with brief accounts of the more recent trends in insect control, aspects of resistance, control appliances and aspects of integrated control are also discussed in a separate section. An insect species-host plant index is also provided as an appendix.

As the writing up of the book was in progress, we felt, that to produce a fully up-to-date book is well nigh impossible, as new information has been accumulating almost everyday. It was therefore decided to restrict details to a level which would be most useful to the Indian student doing postgraduate studies in zoology, agriculture and veterinary sciences. This book will also be a useful introduction to students embarking on research work in entomology. Though the manuscript of this book was completed in 1971, the unexpected and unavoidable delay in its publication has provided us only limited scope to incorporate some of the more recent findings.

It is indeed most unfortunate that a few months before the publication of this long awaited volume, our senior colleague Prof. K.K. Nayar passed away thus removing from amongst us a scientist of calibre, one of our finest entomologists and a pioneer in insect endocrinology in India whose work on *Iphita limbata* has won the admiration of entomologists all over the world. We owe a deep debt of gratitude to him for his inimitable spirit of cooperation and guidance during the preparation of this book.

Many people, institutions and pesticide firms have generously contributed towards the preparation of this book, and we wish to express our sincere gratitude to them. Incorporation of a long list of names may not appear quite feasible, but due acknowledgement has been made at the appropriate places. However, special mention may be made of the invaluable help given by Dr. V.P. Rao, Commonwealth Institute of Biological Control, Bangalore, Dr. W. Buttiker, CIBA-Geigy, Barle, Switzerland, and the US Department of Agriculture in providing numerous photographs. The ungrudging services rendered by Dr. V.K.K. Prabhu, Dr. N.R. Prabhoo, Dr. R.S. Prasad, Dr. G.C. Unnithan, Mr. C.R. Nehru, Mr. A. Fernandez, Mr. R.V. Varma, Dr. V.S. Krishnan Nair and Mr. T.I. Jacob are also herewith acknowledged.

We would be failing in our duty if we do not express our sincere appreciation of our publishers, Tata McGraw-Hill, who spared no pains in their efforts to produce a volume of real quality in spite of all interferences in the smooth production of this book.

We believe that this volume will meet with the general approval of Indian students.

B. Vasantharaj David
T.N. Ananthakrishnan

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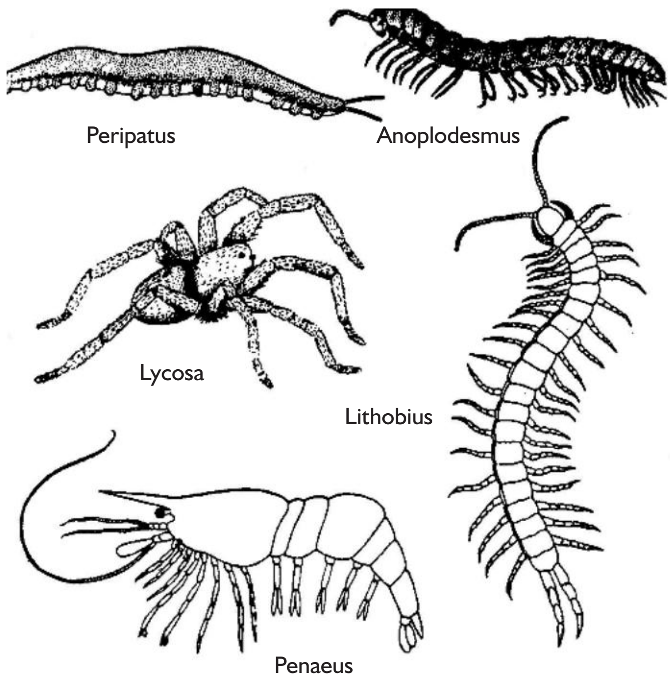
◆ Chapter 1

Introduction

Insects are a highly specialised group of invertebrates belonging to the largest of animal phyla, the Arthropoda, which also includes in it the prawns, crabs, lobsters, centipedes, millipedes, scorpions, ticks, mites, and spiders. It is not an exaggeration to say that practically three-fourths of the animal species come under this phylum. Arthropods are bilaterally symmetrical animals with their bodies divided into a number of rings or segments and covered by an exoskeleton made up of a substance called chitin; with jointed appendages provided with independently movable muscles inserted into special pockets of the exoskeleton; a haemocoelic body cavity containing internal organs bathed in circulatory blood; a dorsal heart and a ventral nerve-cord; and a branching network of tubes for respiration called the tracheal system. *Ecdysis* or moulting is a phenomenon characteristic of all arthropods whereby the cuticle is shed at regular intervals in order to accommodate the growing tissues.

The origin of the arthropods is from an annelid-like ancestor with the body bearing a series of ring-like segments, a simple head, and a ventrally placed mouth. In the course of evolution, each body segment, except the last, acquired a pair of ventral appendages. The head became the most specialised bearing large compound eyes, antennae and other sensory organs. To facilitate in efficient locomotion, these appendages became jointed and with further specialisation some of the anterior pairs of appendages, more notably the first, served to push the food orally. This gradually resulted in the fusion of the first segment of the body with the prostomial region. The fossil trilobites very much reflect this condition. The diversification of the different major groups of the Arthropoda occurred next, leading to the emergence of arachnids, insects, myriapods and crustaceans. The specialisation of the head, consolidating the gnathal segments incorporating segments 2, 3 and 4, whose appendages became the mandibles, maxillae and labium respectively, was the next step. The remaining body segments were more vermiform bearing the locomotor appendages as in the class Myriapoda. It is from the terrestrial myriapod–like ancestors that three distinct lines emerged—(i) the chilopods or centipedes, (ii) the symphylids, pauropods, and diplopods or millipedes, and (iii) insects.

To understand the position of insects in the animal kingdom, it is desirable to have an idea of the related members of the living Arthropoda (Fig. 1.1). The five main groups into which the phylum is divided are: Crustacea (prawns, crabs, lobsters); Onychophora (*Peripatus*); Myriapoda (millipedes, centipedes); Insecta or Hexapoda; and Arachnida (spiders, scorpions, ticks, mites).



▲ **Fig. 1.1** *(Clockwise from top left) Arthropods Peripatus (Onychophora), Anoplodesmus (millipede), Lithobius Penaeus (Crustacea) and Lycosa (Arachnida)*

The Crustacea include forms which are usually aquatic, breathe with gills, and have a body consisting of a head, thorax and abdomen. The head and thorax are mostly fused to form a cephalothorax. The head bears two pairs of antennae followed by a pair of mandibles, two pairs of maxillae, and several paired biramous appendages adapted for a variety of purposes like swimming. Some of the anterior thoracic appendages may be modified for dual functions like feeding and locomotion and are termed the maxillipedes. While a majority of the forms are aquatic (marine and fresh water) and free living, a few are parasitic with reduced body and appendages.

The Onychophora includes a single example, *Peripatus*, exhibiting discontinuous distribution being found in Australia, Africa, South America and parts of the Orient. This is a unique animal with a soft, velvetty skin with dermomuscular body wall devoid of chitin and worm-like in appearance. Its head is made up of three segments with a pair of ringed antennae on the first segment, and a pair of mandibles on the second. Numerous paired, laterally placed segmental appendages ending in claws are characteristic. As in annelids, nephridia are the organs of excretion. The tracheal system has a non-segmental arrangement and the irregularly placed stigmata open into respiratory or tracheal pits. *Peripatus* is a living example, which shows that the arthropods are derived from the annelidan stock. All the same, the dorsal tubular heart, tracheae and the haemocoelic body cavity give it a place among arthropods.

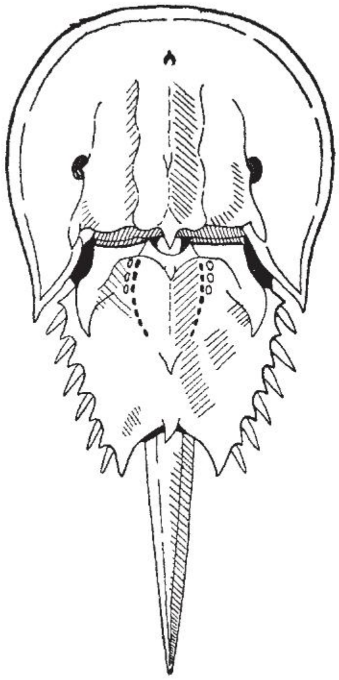
The myriapods are so called because of the numerous paired appendages. They have a six-segmented head and a trunk, bearing numerous leg-bearing segments without differentiation into thorax and abdomen. The millipedes, which are cylindrical in form and curve into a close spiral when disturbed possess a pair of seven-segmented antennae, two pairs of appendages per segment (Diplopoda) and have the gonads opening behind the second pair of legs (Progoneata). The centipedes on the other hand have a flattened body and a segmented antennae, with only one pair of legs per segment (Chilopoda). First pair of which is directed forward to act as poison claws. The gonads open behind on the penultimate segment (Opisthogoneata).

The Symphyla have bodies with 14 segments, each with a pair of appendages, usually a pair of stylets and reversible appendages on the abdomen. The antennae are many segmented and the mouth parts resemble those of the insects. The gonopores are placed on the fourth segment. The Pauropoda are myriapods related to the symphylids and possess trifid antennae. They are abundant in the soil.

Insects have their bodies clearly divided into three regions—the head, thorax and abdomen. The thorax is again tri-segmented—the pro-, meso- and meta-thorax—each with a pair of jointed legs (Hexapoda). Generally two pairs of wings are present, one each from the meso- and meta-thorax. The head bears the antennae, the eyes and the mouth parts comprising the labrum; mandibles, maxillae and labium. The abdomen is basically

11–segmented, without appendages, but the 8th, 9th and 10th segments bear modified appendages for purpose of mating or egg laying.

The arachnids include animals like scorpions, spiders, mites and ticks, with their bodies usually composed of three regions—the prosoma, the mesosoma and the metasoma. The prosoma represents the cephalothorax, the mesosoma the abdomen, and the metasoma the tail. In spiders, the mesosoma and the metasoma are fused to form the opisthosoma. Antennae are absent and eyes are simple. There are four pairs of seven-segmented walking legs. In front of the mouth are the chelicerae or jaws and the pedipalp on either side for grasping the prey. The organs for respiration are tracheae in spiders or special organs called book-lungs in scorpions. Many arachnids are terrestrial and some are aquatic like the water-mites and the marine king crab (*Limulus)* (Fig. 1.2).



▲ **Fig. 1.2** *Limulus (king crab)*

Reasons for the Dominant Position of Insects

Without doubt, insects occupy a dominant position in the animal world, outnumbering all other inhabitants. They are very successful animals. Of the estimated 1.35 million living species of animals, more than 900,000 are insects. Their tenacity for life is amazing and their capacity for multiplication and wonderful adaptations have made them a serious menace to human life and activities.

Insects have developed a great capacity for flight. This has enabled them to migrate and get dispersed, apart from being able to discover their mates, seek food and escape from enemies. Their ability to live in extremes of environmental conditions is most noteworthy, and it is this ability for adaptation that has made it possible for them to invade and colonise almost every nook and corner of the world. Not only are they abundant in places where green vegetation is luxuriant, but they are also found in myriads in dead and decaying organic matter. They also exist as parasites on and in animals, including other insects. They are known to live in crude oil, petroleum, and even in the corks of cyanide bottles that are used to kill them.

Their small size confers many advantages. The smallest insect is about the size of the largest amoeba, and the largest is about the size of a small mouse—the general range spanning from 0.2 to 120 mm. Because of their small size, they occupy very little room even if millions are crowded in a place. And though they consume very small quantities of food, the combined effect of their attack on the host can be devastating.

Reproductive Capacity

In addition to numerical abundance, insects also abound in the number of species. A swarm of locusts is estimated to contain more than 1500 million individuals. Aphids or plant lice are so abundant that there would be 25–30 thousands per plant, while soil insects are estimated to be 2.5–160 millions per hectare. Special adaptations for reproduction are present in most insects, and whenever an insect has a short life-cycle, there are invariably numerous egg laying periods in succession. For instance, in the notorious cottony cushion scale *(Icerya purchasi)*, destructive to orchards, each female lays at a time 500–1,400 eggs, and there are 3-4 broods every year. So even if only 200 survive, the total number at the end of the 4th generation would theoretically be about 160,000,000,000,000. Mention may be made of the traditional example of the housefly where a pair beginning to breed in April, would, if all young ones survive, result in a total of 191,010,000,000,000,000,000 by August. The eggs of most insects are well protected and special methods of reproduction by polyembryony and parthenogenesis step up this multiplication.

Of all the adaptations, it is the nature of the body covering, the chitinous exoskeleton, that confers on insects the maximum advantage. It is strong and rigid, but at the same time flexible because the sclerites or plates are separated by soft membranes. The exoskeleton not only supports the internal organs, but also provides attachment to the numerous muscles, making them independently movable. Under the influence of evolution, the chitinous exoskeleton has been variously modified with the addition of further cuticular material in various ways. This has served to strengthen the head and jaws, and to develop horns, bristles, scales and other structures such as the stout toothed or armed legs for burrowing. A very important advantage conferred on insects by the cuticle is the prevention of loss of water by evaporation, because the cuticle is impermeable to water. Their success as a class depends on their ability to survive in more or less dry environment and hence on their capacity to resist desiccation by conserving water or preventing water loss. Transpiration is prevented by the waxy layer on the cuticle. The spiracles, while admitting air, have a mechanism for closing them at other times and preventing excessive water loss.

Therefore, it may be emphasised that such factors as small size, capacity for flight and hence dispersal, abundance through high powers of reproduction, ability to feed on endless varieties of food materials, presence of a chitinous exoskeleton which serves for protection and water conservation contribute to the success of insects as a group.

Origin, Evolution and Distribution of Insects

Origin The origin of insects dates back to about 350 million years, presumably in the lower Devonian, and on the basis of our understanding of arthropod morphology, the myriapods appear to be closely related to insects. Of the myriapods, Symphyla share more characters in common with the primitive insects and it would not be an over-statement to say that both the myriapods and the insects arose from a common stock or from a myriapod-like ancestor. Evidence of this is seen from the fact that the first instar of many diplopod myriapods shows many features in common with insects, such as a head with six segments, a thorax of three segments, each with a pair of legs, and an abdomen of about five segments, without appendages or with vestigial legs. Further, the fact that among apterygotes, leg-like appendages are present on the abdominal segments and that the Collembola have a short abdomen of six segments, is also significant.

Again the presence of a pair of antennae with a variable number of segments, each supplied with muscles, is a feature common to all myriapods and some primitive insects like Diplura and Collembola. Also of importance are the similarity of the malpighian tubules and tracheal tubes, and the fact that ecdysis occurs through a transverse slit on the hind border of the head in Myriapoda, Protura and Collembola. Looking at the closeness of symphylids to insects, we find that the ⅄-shaped epicranial suture or ecdysial suture is common to many Symphyla and insects, the structure of the post- mandibular appendages are similar as also the nature of the hypopharynx in these groups. The presence of styles and eversible sacs common to Symphyla and Diplura and the terminal cerci of Symphyla appear to correspond to those of insects. Further, the development of Symphyla shows that they have also a trunk composed of 14 segments as in insects. In spite of all these common traits, symphylids are progoneates with the reproductive system opening at the anterior end. However, a single genus *Polyxenella* exists, which, while being a true symphylid, is an opisthogoneate and hence approaches the insect. All the same, the present trend of thinking is towards maintaining that the myriapods, notably the symphylids, stand closest to the insect. Many myriapods have a peculiar hexapod larva, which suggests that the insects could have originated from myriapod-like ancestors by a process of neoteny, i.e. young ones showing sexual precocity.

Several other theories have been put forward about the origin of insects. Handlirsch's Trilobite theory suggests that the insects have developed from marine ancestors, the trilobites. The wings of insects, according to his view, would be, homologous to the paranotal lobes, i.e. the broad lateral extensions of the sides of the segments of trilobites. The trilobites also have, as in insects, a single pair of antennae, compound eyes and three ocelli. This theory has no standing today, because it would mean that the winged insects arose earlier than the apterygotes. Other theories of marine origin of insects were those of Hansen, who proposed their origin from the crustacean group Syncarida, and of Crampton, who advocated that the insects originated from isopods.

Among the theories of terrestrial origin of insects a notable one is that of Tillyard, who believed that both the myriapods and insects have descended from a common hypothetical ancestor, which he called Protaptera. This broke off into two lines: Opisthogoneata and Progoneata. The former again split into the Chilopoda and Insecta. From the insectan branch there was very early branching off of Collembola and Protura, with both the groups having common characters with myriapods. This stem then divided into the entotrophic Diplura and the ectotrophic Thysanura, from which arose the pterygotes.

Evolution It was Mosley (1894) who proposed the diphyletic theory of origin of arthropods, later supported by Haeckel (1896) with increased information on the biology of *Peripatus,* highlighting a close relationship between Onycophora and Tracheata. Snodgrass (1938) suggested another monophyletic scheme of arthropod evolution on the basis of a fossil of a *Peripatus*-like animal and concluded that the hypothetical ancestral group were lobopod annelids. Following chitinisation of the cuticle the lobopods gave rise to the Proto-onycophora from which arose the Onycophora and the Protoarthropoda in which the cuticle became thickened and sclerotized. Protoarthropods gave rise to the Protrilobata and Protomandibulata (Crustacea and Protomyriapoda). From the Protomyriapoda arose the myriapods and insects, showing that Onycophora do not play any part in the evolution of arthropods. The mandibulate arthropods (Crustacea, Myriapoda and Hexapoda) form a natural group, the mandibulata.

In subsequent years the polyphyletic origin of arthropods gained ground based on the evidence from embryology. While the debate as to the origin and evolution of arthropods is still inconclusive, there is an increasing support for the monophyletic origin, with the major groups Crustacea, Myriapoda and Hexapoda having had a common ancestor from a primitive, unsegmented, worm-like animal. The Hexapoda and Myriapoda are sister groups with a common multi-legged ancestor. Among the insects Collembola, Protura and Diplura have entognathous mouth parts and are distinct from the Thysanura and Pterygota which form the true Insecta.

Insects have undergone a vast adaptive radiation, thanks to the evolution of wings. While the paranotal theory indicates that wings evolved from rigid outgrowths of the terga, with their increase in size later developed flexible articulation. The pterygota split into two evolutionary lines, the Palaeoptera and Neoptera.

Distribution Insects enjoy a wide distribution from the equator to the poles. They are found on snowy mountains of the Himalayas, deep beneath the soil, in deserts, hot springs, petroleum, crude oil, fresh water and the sea. This wide distribution is correlated with extremely favourable conditions. They are said to be able to withstand conditions lower than —46°C and they have great migratory powers. It goes without saying that insects are found more in the tropics than in other areas, probably because of the amount of sunshine and consequent luxuriant vegetation. Distribution is brought about by migration and in many cases air currents are responsible for this—the insects being carried by the prevailing wind. Man himself, with his craze for expansion of trade the world over, spreads both the beneficial and harmful insects from one place to another.

Man has been attracted by insects from very early times. In ancient India, philosophical commentaries and literature mention about insects. The Sanskrit term *shatpada* refers to the hexapodous condition of insects. The flight of bees, especially the solitary bees, their association with honey-gathering and visiting of flowers; mud wasps and their nest construction; the erroneous view that the caterpillar, imprisoned in the nest, becomes a wasp by sheer force of thought on the part of the larva; all find mention in Indian folklore. Use of insect and insect products as items of medicinal value (oil beetles, lac, use of red ants in suturing wound where a biting ant is decapitated to hold fast the gape of the wound) have found a place in certain indigenous systems of treatment. Honey is used more as medicine than as food. Parts of insects have been used as cheap jewellery by certain tribes. Elytra of beetles (ochre red, green and blue) have been used to decorate the head gear of Kathakali artists. Other early civilizations (Egyptian, Semitic and Chinese) also have recorded more or less correct information on some insects and their biology.

Entomology, like zoology, has developed as a study of natural history and taxonomy. Till about 1930, morphological aspects of the subject was discussed all over the world. These morphological studies yielded considerable information on the taxonomy of insects, insect pests and control. Towards the later period, applied entomology developed and a fundamental basis for pest study and methods of pest control, including biological and legislative control, formed the major activity in this branch of science. Recognising the usefulness of the insect as an experimental animal, Wigglesworth showed that physiology of insects is a fascinating field of study, and he established insect physiology as a separate discipline in 1930-38. In later years, physiology extended into the field of insect control also, and this resulted in the reunion of subjects that were developing divergently, and formed the new entomology. Emerging in 1950-60, this major discipline showed remarkable developments and a dynamic entomology came into being in the biological sciences. It encompasses morphology, ecology, physiology, phenology, pestology, biochemistry, and ethology (behaviour) of insects.

With a history of over 200 million years behind them, insects have had sufficient time to tackle all the problems that now confront man. Arriving on earth as a result of evolution just a short while ago (150,000 years), man is bewildered by the magnitude and complexities of the problems facing him: overpopulation of his own kind, lack of food, utilisation of other members of society for its own well-being, want of sufficient shelter, and the enemies that attack, infect, worry or kill him. The only other group of social animals that he could hopefully look forward to is that of insects and only a beginning has been made in understanding their lives. Man is indeed struck by the ease with which insect society has tackled the problems mentioned above, and he is only now beginning to realise that learning, packeted and provided for the offspring have contributed to their societal well-being. The patterns of the division of labour, effective planning of population, vigorous steps in midwifery and child rearing, and the understanding of 'language' involving chemical, visual and sonal symbols, which does away with the necessity of learning at the individual level, have all been achieved by inheritance of genetic material perfected through evolutionary steps extending through several millions of years.

History of Entomology in India

Insects have been known from the Vedic times as early as 1200–1000 B.C. as recorded in the treatises of Charaka and Sushruta. A classification of ants, flies and mosquitoes are to be found in Sushruta's treatise *'Sushruta Samhita',* while in *'Charaka Samhita'* we find a classification of bees and even the honey produced by various bees. The term *'shatpada'* (six-legged insects) was coined by Amara Simha, some one thousand years before the European naturalist Latrielle coined the term Hexapoda. Later, several others attempted to classify insects on more precise, biologically based characters as seen in the classification of animals by Umasvati in her work *Tatwarthadhigma*—the classification being based on the number of senses that animals including insects exhibit. Interestingly enough, it was Rao Bahadur Y. Ramacahandra Rao who elaborated Umasvati's classification. It is not the intention of the authors to elaborate on the different classifications except to mention the above as the forerunner of the available information on insects.

It was not until the early 17^{th} century that major advances were made in Entomology. However, in the middle of the 15^{th} century, silk industry in Kumaon and Kashmir was thriving and entomology in modern India should have progressed sometime after the 16^{th} century. The first entomologist to make extensive collections of Indian insects was J.C. Fabricius. Several Christian missionaries and employees of the East India Company were amateur entomologists who collected insects and sent them to taxonomists in Europe. The beginning of Indian Entomology can be traced 1758 when *Systema Naturae* was published. Its Xth edition by Carl Linnaeus contained the earliest record of Indian insects, mentioning 28 species. Fabricius, Edward Donovan, Gerard Koenig, Westwood, and Hope are some notable entomologists during the period 1745 to 1922. The defence forces of the East India Company contributed considerably towards the development of Indian Entomology.

Besides, a number of amateur entomologists of the forest and medical services, and other not so professional and professional entomologists of $19^{th}/20^{th}$ century contributed towards the advancement of entomology. People like Stebbing, a forest entomologist, Buchanan and Cameron of the Indian Medical Service, and Sedjenick and Ollenbach of the Indian Civil Service, besides many others like contributed in large measure to our knowledge of Indian Entomology. Annandale, Ernest Green, *Maxwell Lefroy* and *T. B. Fletcher*. The major volumes *'Indian Insect Life'* by Lefroy and *'Some South Indian Insects'* by Fletcher, *Forest Entomology* by Beeson are even today works of reference. Many manuals on the fauna of British India appeared from 1864 and it was Hampson who contributed first to that series by publishing four volumes on *Moths of India*. Several volumes on Coleoptera appeared with contributions by Guy Marshall (Curculionidae) and Cameron ((staphylinids), Burr on earwigs, Maulik on chrysomelids, Christopher on mosquitoes, to mention a few.

Scientific entomology is over a century old in India, and a firm foundation in economic entomology was laid by entomologists like Lefroy, Fletcher, Ramakrishna Ayyar and Ramachandra Rao (Figs 1.3, 1.4). General entomology received comparatively less attention, and even now in India biologists feel that entomology means only applied

▲ **Fig. 1.3** *(From left) Maxwell Lefroy and T.B. Fletcher*

▲ **Fig. 1.4** *(From left) Y. Ramachandra Rao and T.V. Ramakrishna Ayyar*

entomology. It was between 1900–1950 that there were positions of entomologists in state governments. Entomologists like T. V. Ramakrishna Ayyar, Y. Ramachandra Rao, Richard Coleman, M. Puttarudraiah, H.S. Pruthi, E.S. Narayanan, S. Pradhan, M.S. Mani, and a host of others raised the status of entomology through their contributions and with entomology becoming a special subject in the traditional and agricultural universities. The Bombay Natural History and the Imperial Agricultural Research Institute (now IARI) and Forest College, Dehra Dun, have played an equally important role in raising the status of entomology to the present level.

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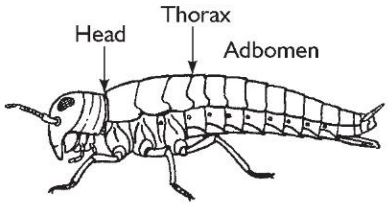
Section One

Morphology

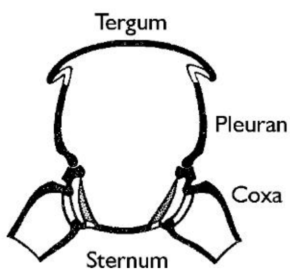
◆ Chapter 2

External Morphology

The Bodies of insects are divided into three distinct regions or tagmata (Fig. 2.1)—the head, a thorax of three segments, and an abdomen primarily composed of 11 segments. The head is connected to the thorax by a flexible neck or cervicum that is strengthened by small sclerites called the cervical sclerites. The head, being the sensory and feeding centre, bears the mouth parts, antennae, compound eyes, and ocelli. The thorax bears three pairs of legs and two pairs of wings. The abdomen bears the genital openings and the egg laying apparatus of the female at the posterior end. As is characteristic of all arthropods, each segment of the body in the thorax and the abdomen is composed of distinct chitinised plates or sclerites, a dorsal tergum, ventral sternum, and lateral pleural plates (Fig. 2.2).



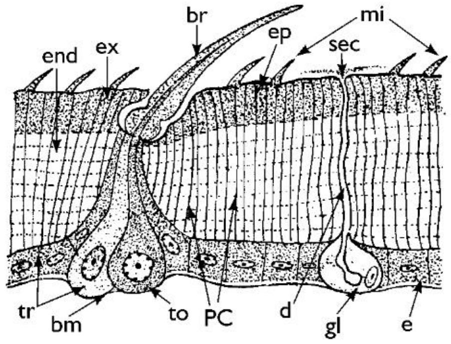
▲ **Fig. 2.1** *Body divisions of an insect (Snodgrass, Principles of Insect Morphology (McGraw-Hill Publishing Co. New York, 1935).*



▲ **Fig. 2.2** *Cross-section through body of an insect at the thoracic region to show sclerites (ibid)*

The Integument

The body wall or integument of insects (Fig. 2.3) consists of a layer composed of living cells—the epidermis or hypodermis—resting on a basement membrane. The epidermis secretes an outer non-living cuticle, consisting basically of a chitin-protein material. This is deposited on the outer surface of the epidermal cells and harden to form the exoskeleton. The exoskeleton not only forms the outer covering for the body, but also lines the foregut, hindgut, and the tracheal tubes, besides facilitating muscle attachment by forming in-growths or pockets. The cuticle consists of three layers, an outermost, rather thin layer (0.03–0.04μ) called the epicuticle, a much thicker layer —the exocuticle—below it, and next to it the endocuticle which is the thickest layer. The exocuticle and the endocuticle together constitute the procuticle. The epicuticle is a very delicate layer without any chitin, often containing other compounds such as sulphur and some fatty substances. In some insects this layer appears to be further divided into very fine layers as follows:



▲ **Fig. 2.3** *Section through the body wall of insect. bm: basement membrane br: seta. d: duct of gland (gl) e: epidermis. end: endocutide. ep: epicuticle. ex: exocuticle. mi: microtrichia. PC: pore canal. sec: secretion. to: tormogen. tr: trichogen.*

- A cuticulin layer is evident as a thin membrane over the surface of the epidermal cells and this layer in turn is strengthened by droplets rich in polyphenol and is also called the polyphenol layer. Like the sclerotin of the exocuticle, it is highly resistant to acids and organic solvents.
- A thin layer of wax or waxy layer or lipid epicuticle.
- A thinner layer or covering called the cement layer or tectocuticle. This epicuticle may be folded in various ways and may bear small spines or microtrichia.

The exocuticle contributes to the rigidity or toughness of the cuticle and consists mainly of chitin and proteins. It is pigmented by a hard, brown material and is referred to usually as being ‘tanned’. In regions of the integument which are more flexible, the exocuticle is wanting or considerably reduced. The endocuticle also contains chitin and proteins and as this layer is not tanned, it is more soft and flexible. It is made up of fine horizontal lamellae and represents the layers deposited in succession during development. There are also numerous fine vertical lines traversing both the exocuticle and endocuticle and are often referred to as pore canals. Several functions are ascribed to the pore canals, the more important ones involve transportation of oxidising enzymes used in sclerotisation to the epicuticle as well as transfer material used in repair of wounds.

Chemical Composition of the Cuticle

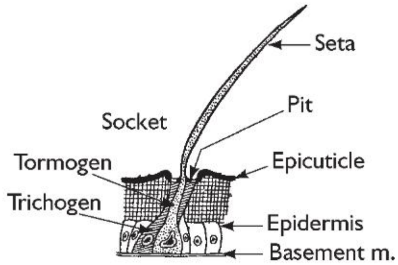
Chitin which makes up the exocuticle and endocuticle is a nitrogenous polysaccharide and often constitutes 25–60% of the dry weight of the cuticle. It is insoluble in water, alcohol, organic solvents, dilute acids and concentrated alkalies. On heating with concentrated potassium hydroxide at high temperatures, chitin is converted into chitosan which gives a deep violet colour with iodine. This test for chitin is referred to as Van Wisselingh's test. Another test for chitin is to treat it with a solution of chlorine dioxide in 50% acetic acid (called diaphenol) in a dark room when it turns soft and colourless. Further, chitin gives a violet colour with zinc chloride and iodine.

A mixture of several proteins which forms the major portion of the non–chitinised substances of the cuticle amounts to about 25–37% of the dry weight of insect cuticle and is often referred to as 'arthropodin'. In certain places, as in the tendons of the wings and in the elastic regions of the thorax, there is a rubber-like protein called resilin. The horn-like nature of the exocuticle is not due to chitin but is more due to the presence of an insoluble material comprising tanned protein called sclerotin. The hardness of the cuticle—sclerotisation—is due to interaction of proteins with tanning agents involving various phenolic substances. In some insects, notably the aquatic insects, lime is deposited in the cuticle and removal of the lime with acids makes the cuticle transparent. Basically, therefore, in most insect cuticles proteins can be recognised as water-soluble fractions, the arthropodin, and a water-insoluble portion—the sclerotin—which is the alkali-soluble portion.

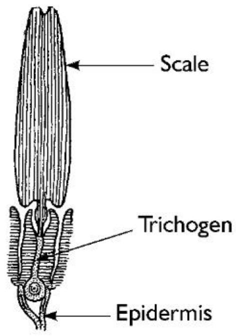
Tanning in the adult cuticle has been attributed to a peptide hormone called bursicon, produced by the neurosecretory cells of the brain and released from the thoraco-abdominal or abdominal ganglia. First discovered in blowflies, bursicon has been detected in cockroaches, locusts, milkweed bug, waxmoth, and mealworm.

The innermost layer of the integument is the hypodermis, which is the continuous layer of living cells. It is from these cells that secretions pass to the outer layers of the cuticle, as well as the moulting fluid which dissolves and absorbs most of the old cuticle when the insect moults. The cuticle is laid down in stratified layers. Vertical passages are found through these strata in the form of fine channels carrying secretions out and also fine spiral channels of unknown function.

Sclerotised areas are often joined by membranous folds. The meeting of two sclerites is termed a suture. Some sutures are seen on the surface of the sclerites which correspond to apodemes. These sutures are infolds of the integument and collectively called the endoskeleton. The apodemes are normally in the form of ridges, plates or arms, serving a mechanical function. The membranous areas of the integument permit free movements of various parts of the body such as distention of the abdomen and making possible inhalation and exhalation during respiration.



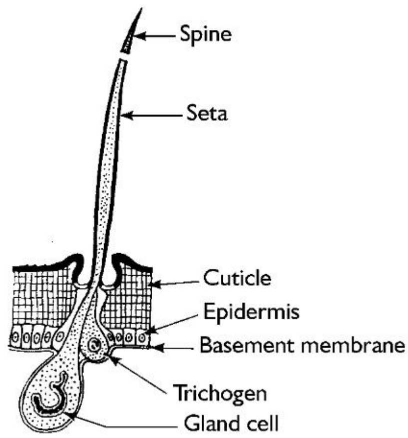
▲ **Fig. 2.4. a** *Seta of insect (Snodgrass, 1935)*



▲ **Fig. 2.4. b** *Scale on insect body (ibid)*

Pigmentation of the Integument The integument often shows extensive colour pattern, mostly due to pigments found in the endocuticle or the hypodermal layer. The common colours are brown, black (melanin), yellow and red (carotenoids). The melanins, the carotenoids and the pterines (white) are the commonest of the insect pigments. Red pterines: called ommochromes, often associated with the eyes are also insect pigments. Another insect pigment is the comparatively rare anthroquinone of which cochineal (carmine) red, and the lac are well known. Metallic colours in insects are not due to the presence of pigments but are caused by the interference among light rays penetrating the thin layer of exocuticle. The general significance of colours in insects is not clearly understood and it has often been mentioned that they are mere waste products as well as ornamental. But in some cases at least, pigmentation has been exploited advantageously by insects. Such examples are the leaf mimic butterfly *Kallima*, the green caterpillars that feed on foliage, the threat marks on insects looking like the eyespots in *Nyctipao*, and the snake-head marks on caterpillars of *Leucorhampha*, the warning colouration of beetles and moths (*Zygaena*), and the various mimics which are of the Batesian type.

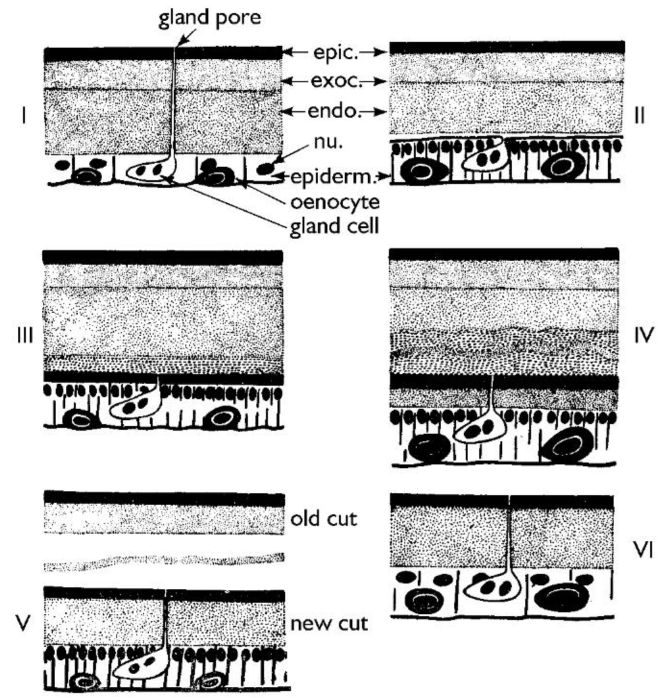
The integument bears processes of different kinds, both internal and external. While the internal processes are confined to the apodemes, several external processes such as cuticular outgrowths like spines, hairs or tubercles, are characterised by the absence of membranous articulations. These are also called non-cellular processes or microtrichia. Setae proper are macrotrichia (Fig. 2.4) which are hollow outgrowths of the entire body wall lined by a layer of epidermal cells. They may be of various shapes, but essentially they have a membranous articulation. The base of the seta is set in a small setal membrane, depressed in a hair socket or alveolus. The epidermal cell forming a seta is called a trichogenous cell or a trichogen. Closely associated with it is another cell forming the setal membrane, which forms the floor of the socket and called the tormogen. On the legs of many insects are numerous spurs, which, unlike the setae, are of multicellular origin. Of the several types of setae seen in insects, mention may be made of clothing hairs covering the general body surface, scales seen on the wings of butterflies and moths, glandular setae—functioning as outlets for secretions of hypodermal glands, and sensory setae—sensory in function and connected with the nervous system—usually found on appendages.



▲ **Fig. 2.4 c** *Poison seta of caterpillar (ibid)*

Dermal Glands

Numerous ectodermal glands which are groups of specialised cells of the epidermis occur in insects. They discharge their secretions externally. Some of the common ectodermal glands are the wax glands, lac glands, scent glands, poison glands, mucous glands, etc. Wax glands occur in the honeybee, scale insects and mealy bugs; lac glands secrete lac; several others produce secretions which have a pungent odour and act as repellents. In many plant bugs, the repugnatorial glands of the sixth and seventh segments of the abdomen and the pygidial glands of some beetles are common examples. Located on the wings of some male Lepidoptera are scent scales called androconia, which have gland cells at their base. These secrete a fluid meant to attract females. Hypodermal poison glands associated with setae or spines are present in the larvae of some slug caterpillars, saturniid moths etc. Still other secretions cause irritations.



▲ **Fig. 2.5** *Moulting steps in ecdysis. I–VI represent stages. (R.F. Chapman, The Insects, The English University Press Ltd. London, 1969). epic—epicuticle, nu–nucleus old, cut–old cuticle, endo–endocuticule epiderm–epidermis new, cut–new cuticle.*

Moulting

It was mentioned earlier that before becoming adults, every arthropod has to cast periodically its skin in order to accommodate the growing internal organs, and this process is called ecdysis or moulting. The moulted skin is termed the exuviae. The number of moults varies with different insects. Prior to ecdysis, the old cuticle splits, invariably beginning at the top of the head. This rupture of the old cuticle is along a predetermined line of weakness and further splitting is quickened by muscular contractions of the body. The mechanism of moulting appears to be aided by a fluid secreted by the epidermal cells or special glands of the epidermis called the moulting glands. It is this secretion that helps to dissolve the endocuticle and frees the rest of the cuticle during moulting.

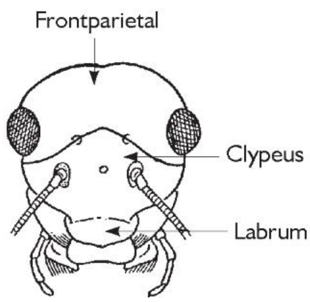
The series of steps involved in moulting are given in Fig. 2.5. The moulting fluid contains enzymes (proteinase and chitinase) useful in digesting the endocuticle. Secretion of the moulting fluid is followed by the secretion of cuticulin and it is after the laying down of the cuticulin that the enzymes mentioned above get activated. Already, an active epidermis would have undergone mitosis under the influence of hormones to change in size and shape. This generates a tension pushing the cuticle off the epidermis (apolysis). In the intervening space moulting fluid digests the endocuticle, while the cuticulin pushes from underneath. The old exocuticle then gets thrown away and the cuticulin with its underlying procuticle produced by epidermis becomes thick and strong. This forms the new cuticle. Variations occur in several insects, but the general plan of moulting is as indicated above.

◆ Chapter 3

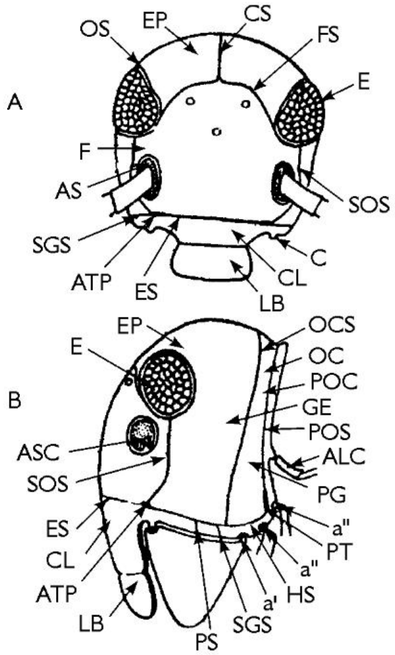
The Insect Head

The head of an insect is an almost completely sclerotised capsule formed by the fusion of several sclerites, often distinctly seen in the embryo. It differs in shape and size in different insects. It bears a pair of compound eyes, simple eyes or ocelli, often three in number, a pair of antennae, and mouthparts. Based on the inclination of the long axis and the mouth parts, it is usual to distinguish three types of heads. They are the hypognathous head with the mouthparts ventrally placed, the long axis of the head being vertical; the prognathous head, with the mouthparts placed anteriorly; and the opisthognathous head, with the mouthparts placed between the anterior pair of legs and head directed backwards.

Taking the generalised insect cranium (Fig. 3.1), we find two distinct regions: an anterior facial or frontoparietal region and a posterior occipital region. The fron-toparietal region includes a median frontoclypeus and two lateral genae. The frontoclypeus is usually divided into an anterior frons and a posterior clypeus separated by the frontoclypeal suture. The clypeus is bound posteriorly by an espistomal suture and is more or less divisible into anteclypeus and postclypeus. Separating the frontoclypeus and the lateral genae are two frontogenal sutures. The dor-

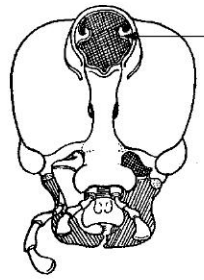


▲ **Fig. 3.1** *Front view of the head of an insect (Snodgrass, Smithsonian Misc. Coll.* **142***, 1960)* sal region of the head is the epicranium, of which the part just above the frons and between the compound eyes is called the vertex. The epicranium is divided by a median epicranial or coronal suture (Fig. 3.2) which bifurcate into two arms, the frontal sutures. The ⅄- shaped suture dividing the epicranium is the line of ecdysial cleavage and it is along this line that the immature insect breaks open at moulting. It is a line of weakness along which the cuticle splits at ecdysis and as the pigmented exocuticle is not developed along this line, it appears as a weak, pale line. It is present in some immature insects and some generalised insects.



▲ **Fig. 3.2** *Front view of the insect head (Snodgrass, 1935) A–showing the epicranium (EP), CS–(coronary suture), FS–frontal suture, F–frons, CL–clypeus bearing labrum (LB), B–side view of the head showing occiput (OC), OCS–occipital suture*

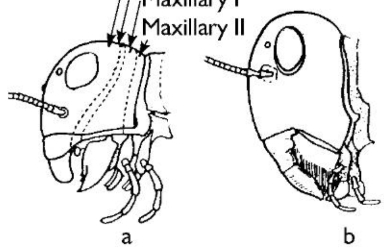
The occipital region lying between the vertex and the neck is separated from the frontoparietal region by the occipital suture. This region partly surrounds the occipital foramen, which is the opening that connects the cavities of the head and thorax. The occipital region is divided into an anterior occipital arch and the posterior narrow postocciput by a postoccipital suture, almost parallel to the occipital suture. Lying lateral to the occiput are the postgenae, wherein is located the articulations of the mandibles and the maxillae. The postocciput bears a pair of small lateral processes, the occipital condyles for articulation with the cervical sclerites (Fig. 3.3).



▲ **Fig. 3.3** *Back view of the insect head (ibid)*

Segmentation of the Insect Head

It was mentioned earlier that the head is a composite structure formed by the fusion of several metameres. As to the number of metameres composing the head, views differ. However, in the early stages of development, the germ band becomes differentiated into an anterior broadened bilobed part—the cephalic lobes or blastocephalon—and a narrow posterior region, the blastocorm. This becomes segmented and the anteriormost segment is called the intercalary segment or the second antennal segment. This becomes fused early with the unsegmented blastocephalon to form the protocephalon. Below the intercalary segment are added three more segments, the gnathal segments or the mandibular and two maxillary segments. Later in development, the mandibular and the two maxillary segments become incorporated with the protocephalon to form the head proper (Fig. 3.4).



▲ **Fig. 3.4** *Segments of the head of the insect; (a) the developmental stage and (b) the condition seen in the final stage (Snodgrass, 1960)*

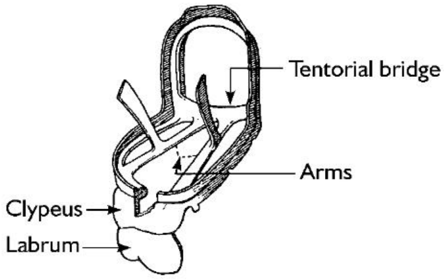
The presence of the intercalary segment is denied by some. The parts derived from the blastocephalon are believed to be homologous with the prostomium of annelids. Recent views on the segmentation of the insect head suggest that the head is made up of six segments. This is confirmed by embryological studies, through the number of paired embryonic ganglia or neuromeres, the presence of coelomic sacs, and the presence of paired appendages.

The segments are referred to as (1) preantennary segment bearing the protocerebrum; (2) Antennary segment bearing the antennae and the deutocerebral ganglia; (3) the intercalary segment which like the preantennary is embryonic and has the neuromere called tritocerebrum; (4) the mandibular segment bearing the mandible; (5) the maxillary segment; and (6) the labial segment with the last three ganglia fusing to form the suboesophageal ganglion.

Another view suggests seven segments incorporating a distinct labral segment in front of the preantennal and with a distinct coelomic sac.

The Tentorium

This is the endoskeleton of the head (Fig. 3.5) which is an internal cuticular framework developed as a result of the ingrowth and fusion of some—2 or 4 pairs of cuticular ingrowths—of the apodemal arms from the exoskeleton. It serves to strengthen the stomodaeum. The two pairs of cuticular invaginations are referred to as the anterior tentorial arms and the posterior tentorial arms. The anterior arms in pterygotes take their origins near or in the subgenal suture, above the bases of the mandibles. The points of origin are termed the anterior tentorial pits. Similarly the posterior tentorial arms arise from the posterior tentorial pits, lying in the lower ends of the post-occipital suture. The position of the tentorial pits are marked externally. In many insects a pair of secondary outgrowths, the dorsal arms, extend from the anterior tentorial arms through the head wall near the antennal bases. The posterior tentorial arms generally become united to form a structure, the transverse bar, being termed the tentorial bridge. The tentorium serves to provide attachment to the ventral muscles of the mouthparts and also support the lower end of the cranial walls. The antennal muscles also arise from the tentorium. The pterygote tentorium undergoes numerous variations. In many insects, as in Orthoptera, the central part of the composite tentorium becomes enlarged to form a broad plate referred to as the corporotentorium. In other cases, the anterior arms may become reduced or absent leaving only a transverse tentorial bridge, while in others even the tentorial bridge becomes reduced to small lateral processes. Rarely, however, the tentorium may be completely lacking.

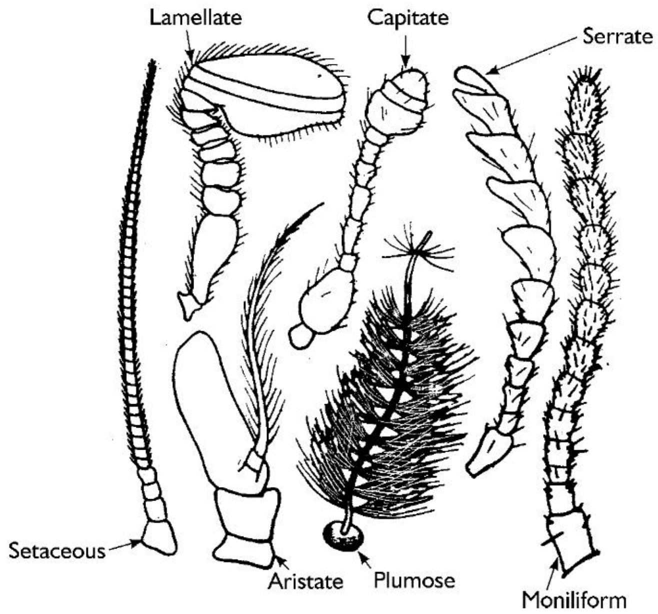


▲Fig. 3.5 *Tentorium inside the cranium of the insect (Snodgrass, 1935)*

Appendages of the Head

From the segmentation of the head, it is evident that the compound eyes, the antennae, the labrum, the mandibles, the maxillae, and the labium are the typical appendages of the head.

Antennae The antennae (Fig. 3.6) which have a sensory function, consist of a pair of movable jointed appendages, mostly tactile. In primitive insects like Collembola and Diplura all the antennal segments, except the last, contain muscles, while in others only the basal segment carries muscles. The shape, size, and the number of segments vary in different insects and in general the antenna is made up of three regions—the first segment called the scape, the second called pedicel, and the third called the flagellum. The pedicel contains sense organs, the organs of Johnston. The antenna as a whole is movable in all directions. The flagellar units are of varied size, and Imms suggests use of the term flagellomeres to the segments.



▲ **Fig. 3.6** *Antennae of insects—Various types*

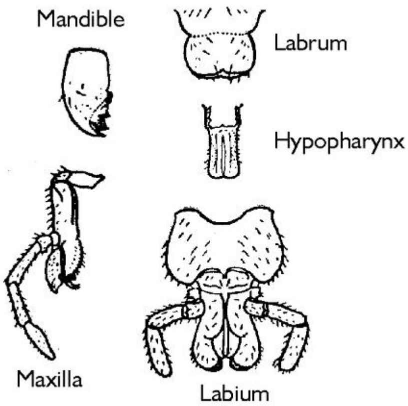
At least 11 types of antennae have been identified they are as follows:

- Setaceous. These taper from the base to the apex as in the cockroach.
- Filiform. These thread-like antennae form almost cylindrical, uniform-sized segments as in grasshoppers.
- Moniliform. These are beaded as in termites.
- Serrate. These are saw-like with the segments having short, triangular projections on one side as in buprestid beetles.
- Pectinate. These are comb-like as in male moths.

- Clubbed. These are clavate as in butterflies.
- Lamellate. These are antennae with the terminal segments expanded laterally to form round or oval sheath-like lobes as in scarabaeids.
- Capitate. These are antennae with the terminal segments becoming enlarged as in nitidulid beetles.
- Geniculate. These are elbowed antennae, with a sharp bend, and long first segment as in weevils.
- Plumose. These are feathery as in mosquitoes.
- Aristate. These are antennae with the last segment usually enlarged and bearing a conspicuos dorsal bristle, called arista, as in flies.

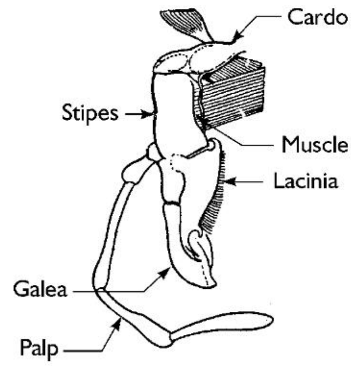
Mouthparts of Insects

Mouthparts of insects generally consist of the labrum or the upper lip (with the closely associated epipharynx), a pair of mandibles or jaws, a pair of maxillae, the labium or the lower lip, and the hypopharynx or tongue (Fig. 3.7). The mouthparts undergo various modifications in relation to the modes of feeding. It would appear convenient to describe in detail the mouthparts of a generalised insect and for this purpose the mandibulate structure of the grasshopper, cockroach, and cricket is given here.



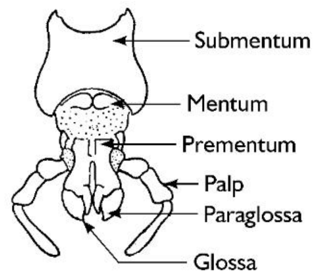
▲ **Fig. 3.7** *Mouthparts of a cockroach (Mandible and maxilla of only one side)*

The labrum is a broad, transverse, flap-like, bilobed structure, attached to the clypeus by a thin articular membrane, allowing vertical freedom of movement. There is an inner lining to the labrum, formed by the reflection of the labral integument, continuous with the dorsal wall of the pharynx. This inner wall is termed the epipharyngeal wall, and frequently bears a lobe—the epipharynx. Lying below the labrum are a pair of strong, sclerotised mandibles provided with sharp cutting edges. In grasshoppers, however, there is a distal incisor region with cutting teeth and a proximal molar region with grinding teeth. The mandibles have two articulations with the head, the anterior and a posterior, and constitute the hinge joint. Situated behind the mandibles and acting as auxiliary jaws are the maxillae (Fig. 3.8) with a basal plate articulating with the hypostoma and attached to the cranium by a membrane. This basal plate is divided into two sclerites—a proximal cardo and a distal stipes. A small sclerite, the palpifer, is usually situated on the stipes and bears the five-segmented maxillary palp. On its distal end the stipes bear two processes, an inner more or less elongate jaw-like process called lacinia and an outer lobe, the galea. The floor of the preoral cavity bears a tongue-like prolongation, the hypopharynx which is usually attached to the inner wall of the labium. The ducts of the salivary glands open on or near the hypopharynx. In some generalised insects it consists of three lobes, a median lingua and two lateral superlinguae. The latter are usually lost in most of the insects.



▲ **Fig. 3.8** *One maxilla of cockroach with its muscles (Snodgrass, 1935)*

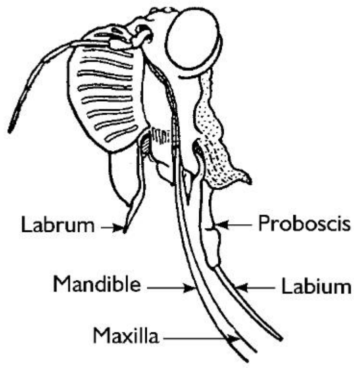
The labium (Fig. 3.9), forming the posterior wall of the gnathal region of the head, consists of a broad plate, the postmentum, secondarily subdivided into a proximal large submentum, and a distal mentum. Attached to the mentum is a bilobed preme-ntum bearing laterally a pair of three segmented labial palpi which arise from small lobes called the palpigers. The mentum also bears two pairs of unsegmented appendages, a median glossa, and lateral paraglossae. These become fused in grasshoppers and beetles to form the ligula. The preoral food cavity leads dorsally into the mouth, between the hypopharynx, the mandibles and the labrum.



▲ **Fig. 3.9** *The parts of labium (ibid)*

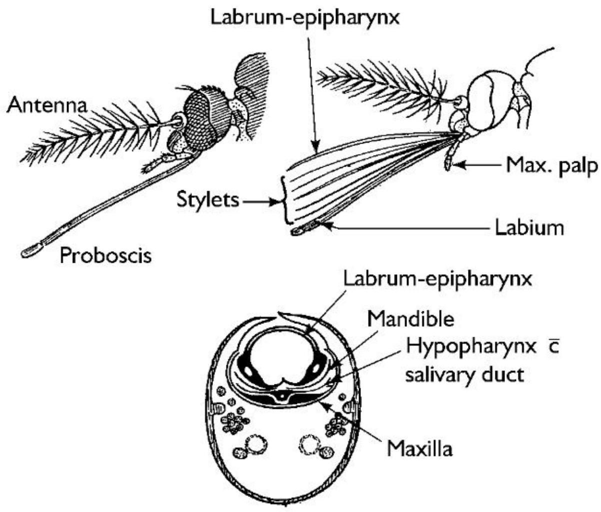
Principal types of Mouthparts Insects feeding on solid material have strong mandibles adapted for cutting and grinding as in the case of the grasshopper's mouthparts described above. Such mouthparts are said to be mandibulate, and occur in Thysanura, Orthoptera, Dermaptera, Dictyoptera, Odonata, Coleoptera, and in the larvae of many insects. Many other insects like the butterflies feed on liquid food and have mouthparts adapted for sucking. Several modifications of the suctorial mouthparts occur, such as the rasping and sucking type seen in thrips, the piercing and sucking type seen in bugs and mosquitoes, sponging or lapping type in the houseflies, the typical sucking or siphoning type in butterflies and moths, and the chewing and lapping type in honeybees.

Mouthparts of a Bug The proboscis or rostrum (Fig. 3.10) of a bug is made up of a rather slender segmented labium which is kept apposed to the central region of the bug between the forelegs. Lying at the base of the rostrum is a triangular lobe, the labrum. The labium is sheath-like and its grooved channel encloses the piercing stylets, four in number. The mandibles form the outer pair, and the maxillae lying between the mandibles, the inner pair. Lying at the posterior part of the beak between the bases of the piercing stylets, and projecting into the proximal parts of the proboscis, is a small conical lobe—the hypopharynx—the anterior wall of which is continued dorsally into the chamber of the sucking pump. The common salivary duct opens into the salivary pump which discharges the salivary secretions at the apex of the hypopharynx into the salivary canal. The inner sides of the maxillary stylets are grooved and the two stylets interlock enclosing a suction canal. The mandibles are the chief piercing organs and the maxillary stylets are inserted into the puncture caused by the mandible. As the stylets are penetrating, the head is brought closer to the leaf surface. The labium now becomes shortened by bending. The inner surfaces of the maxillae are grooved to form two tubes or canals, one of which is the feeding channel connected with the pharynx and the other the salivary channel through which saliva flows down.



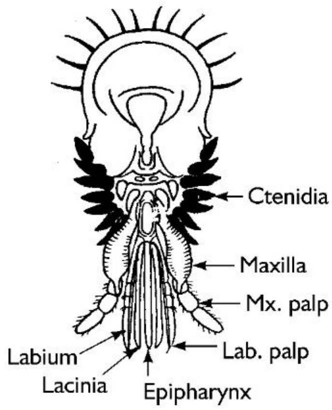
▲ **Fig. 3.10** *Proboscis and head of a cicada (ibid)*

Mouthparts of a Mosquito As in the case of the bug, the labium forms the proboscis (Fig. 3.11). It is elongated and grooved, forming a channel in which the piercing stylets consisting of the slender, needle-like mandible, maxillae, and hypopharynx are found. These are enclosed above by the labrum which is also grooved so that both the labium and the labrum together form the proboscis. The labrum is closely associated with the epipharynx and is so called the labrum-epipharynx. The piercing stylets include a pair of short, fine, stylets—the mandibles—a pair of coarser stylets—the maxillae with palps—and a median stylus—the hypopharynx. The maxillary palps lie outside the proboscis, projecting from its base. They are long in male mosquitoes and in the female *Anopheles*, but very short in the females of *Culex*. During feeding the stylets are thrust into the skin of the host. Through the hypopharynx, saliva is poured into the wound to prevent clotting. By a sucking action of the pharynx blood is sucked up into the tube and this passes through the epipharyngeal groove into the buccal cavity. The labium does not pierce but folds up or down as the stylets pierce the host.



▲ **Fig. 3.11** *Proboscis of a female mosquito (Snodgrass, Smithsonian Misc coll.* **107**, *1944) Top left : Head showing proboscis; Top right: Components of the proboscis viz., labrum, epipharynx, stylets and labium. Bottom Cross-Section of proboscis.*

Mouthparts of a Flea As in mosquitoes and bugs, the mouthparts of fleas are also adapted for piercing and sucking (Fig. 3.12). The labrum and the epipharynx are fused as in the mosquito. The hypopharynx is a small triangular plate, pierced by the salivary ducts at its apex. It takes no part in feeding and cannot even transfer saliva to the wound as it is very short. The mandible of each side are juxtaposed within the epipharynx to form a distinct channel. This channel has also a groove through which the saliva is transmitted. The mouthparts project downwards and the maxillary palpi are very conspicuous, projecting in front of the head like antennae. In shape, the labrum-epipharynx is slender and flattened on its ventral side to join with the mandible. The mandibles are broad blades the distal ends of which are beset with minute, hook-like teeth. The maxillae are peculiar, consisting only of a conical chitinous piece to which are attached the four-segmented maxillary palpi. The labium consists of two lateral halves united basally to a median piece. The paired portions are referred to as palps and consist of four joints. The two palps form a sheath in which the mandibles and the labrum-epipharynx are concealed while at rest. The descriptions given above briefly indicate some varieties of the modifications undergone by mouthparts in insects. Brief descriptions of mouthparts of other insects like the honeybee, butterfly, etc. are given in the chapter on classification.



▲ **Fig. 3.12** *Mouthparts of a flea: ventral view (Herm, Medical Entomology, Courtesy: Macmillan & Co)*

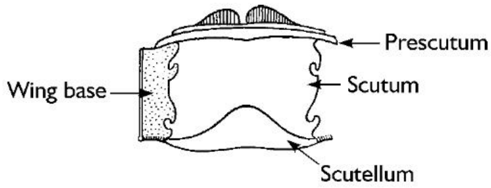
◆ Chapter 4

The Thorax

The thorax which forms the second major division of the insect body is connected with the head through a flexible neck or cervicum, strengthened by thin chitinous plates, the cervical sclerites. The thorax consists of three segments, the prothorax, the mesothorax, and the metathorax. The thorax is the locomotor region of the insect, since the legs and wings originate here. Each segment of the thorax bears ventrally a pair of legs, while the wings arise from the sides of the mesothorax and metathorax. In some of the lower insect orders, as in Orthoptera, as also in some higher insects like Coleoptera, prothorax is generally free, large and conspicuous. In many higher orders the prothorax is much reduced and often inconspicuous. In winged insects, mesothorax and the metathorax are usually fused together as the pterothorax and form a composite unit but in the larval insects and wingless insects they are distinctly separated by a conspicuous inter-segmental membrane.

The Thoracic Terga

The terga of the thoracic segments arranged from anterior to posterior end are referred to as pronotum, mesonotum, and metanotum. In the apterygotes and larvae of insects, the tergum of each thoracic segment is undivided and called the notum. While this condition is retained in the prothorax of most of the adult winged insects, the mesonotum and metanotum are generally divided into three distinct sclerites, the prescutum, the scutum and the scutellum, (Fig. 4.1). A number of sulci or grooves are visible externally and these mark the position of internal ridges or inflections. These sulci divide the tergum into a number of sclerites. At the anterior margin of the pronotum is a narrow groove or suture, the antecostal suture. Lying in front of it is a narrow acrotergite and behind this is the prescutum. Thus there are four distinct tergal components in a typical winged insect. The scutum is always prominent and bears laterally the anterior and posterior notal wing processes serving to articulate the wings. Expanded plates are generally present at the base of the antecostal region and are called the phragmata. These give attachment to the dorsal longitudinal muscles helping in the down stroke of the wing. The phragmata are very characteristic of the mesonotum, metanotum and first abdominal tergite. Sometimes a distinct sclerite, the post-scutellum, is present in the mesothorax formed by the fusion of the antecosta and the acrotergite of the metathorax and becomes closely associated with the posterior end of the mesothorax. This is characteristic of some Hymenoptera and Diptera and in such cases the antecosta and acrotergite of the metanotum are absent.



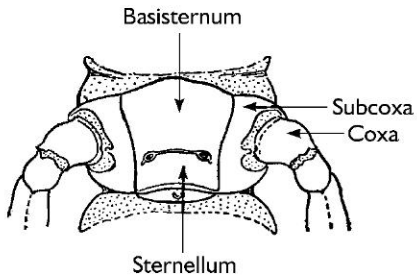
▲ **Fig. 4.1** *Wing-bearing tergal plate (Snodgrass, 1935)*

The Pleuron

In primitive insects, such as the apterygotes, evidence exists for the origin of the pleuron by modifications of the basal segments of the leg or subcoxa. In all winged insects this basal segment of the primitive leg is fully incorporated into the body wall to form the pleuron. The pleuron is similar in all the three segments and is referred to as the propleuron, and the ptero-pleuron. The pleuron is divided by a usually oblique pleural suture (strengthened by a pleural ridge) or sulcus, with an anterior episternum and a posterior epimeron. The internal reflection—the pleural ridge—marking the position of the pleural suture, ends ventrally in an articulating process called the pleural coxal process. The articular membrane between the episternum and the coxa usually bears a small sclerite, the trochantin, quite conspicuous in primitive insects and tending to get reduced or atrophied in higher insects. Dorsally, the pleural ridge terminates in the pleural wing process. The epimeron and the episternum may become subdivided into smaller sclerites called epipleurites lying at the base of the wing in the membrane between the pleuron and the wing base. When these lie anterior to the pleural wing process they are called basalar plates and when posterior, they are termed subalar plates.

Sternum

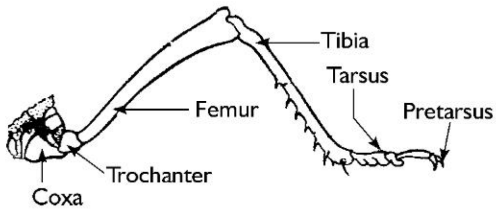
As in the tergum, the sternum of the prothorax, mesothorax, and metathorax consists of a segmental plate or eusternum divided into three main regions—the presternum, the basisternum, and sternellum—but the presternum is invariably absent (Fig. 4.2). Unlike in the tergum, the degree of sclerotisation of the sternal sclerites is very varied. A large basisternum, a small intersegmental spinasternum and the two coxosternites, adjacent to the coxal cavities of the legs are generally distinct. Arising from the eusternal plates are paired sternal apophyses or furcal arms, which in higher insects become fused to form a forked endoskeletal structure, the furca. The sternal apophysis serves to support the longitudinal, ventral, and thoracic muscles. In most winged insects a distinct ridge or sternocosta is present connecting the bases of the sternal apophysis, and this portion is marked externally by the sternocoxal suture. This divides the eusternites into an anterior basisternum and a posterior sternellum or furcasternum.



▲ **Fig. 4.2** *Sternum of thorax with leg bases (ibid)*

Legs

The legs of all modern insects are typically made up of the segments, coxa, trochanter, femur, tibia, and tarsus, terminating distally in the pretarsus (Fig. 4.3). It was mentioned earlier that in all primitive insects one more segment, the subcoxa, was distinct and with its incorporation into the pleural region, it is rarely recognisable as a segment. Between the segments, the joints consist of membranous rings called the articular corium. The coxa is the functional base of the legs, articulating with the pleuron of its segments proximally and distally bearing anterior and posterior articulation with the trochanter. At the base of the coxa is a ring-like suture forming a distinct internal ridge, called respectively the basicostal suture and the basicosta, and it is to the latter that the muscles are attached. Sometimes the coxa articulates with the trochanter but rarely with the sternum. When the lateral post-articular area of base of the coxa becomes enlarged and lies posterior to the basicostal suture it is called the meron, very characteristic of the Neuroptera and the Lepidoptera. The trochanter is a small segment, sometimes divided into two segments, not movable on each other. The trochanter is usually freely movable by a hinge on the coxa.

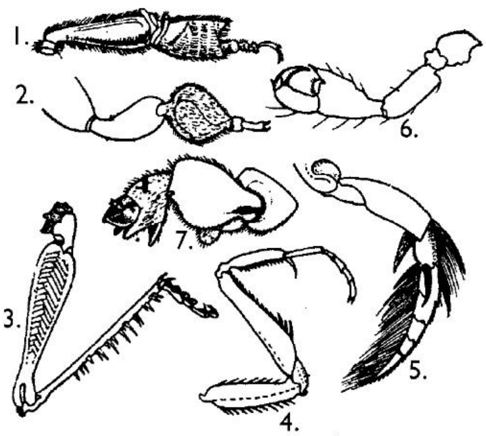


▲ **Fig. 4.3** *A thoracic leg of an insect (ibid)*

The femur is generally the largest and the strongest segment of the leg and in the hind limb of Orthoptera it is very much enlarged for leaping. The tibia following the femur is normally pressed against the lower surface of the femur and is a slender segment. The tarsus is usually made up of two to five segments, the tarsomeres, but in the larvae of primitive insects it is unsegmented. On the lower surface of the tarsal segments are small pads, the pulvilli or the plantulae. The terminal part of the leg, the pretarsus, in the adults and larva bears a pair of movable lateral claws and between them is a median pair, the arolium, and a median bristle—the empodium. On the ventral surface of the pretarsus there is a median unguitractor plate to which the muscles which serve to retract the claws are attached.

Functional Modification of the Legs

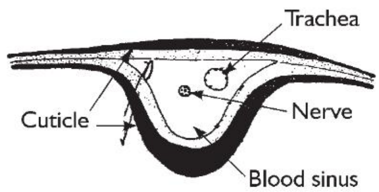
While the legs are normally adapted for walking, many insects have them modified (Fig. 4.4) for a variety of functions. In the grasshoppers and crickets, the hindlegs are saltatorial, adapted for leaping or jumping. The femur is greatly enlarged, giving articulation for the large muscles of the tibia which are used in jumping. In the praying mantis the forelegs are raptorial, modified or grasping the prey. The legs are modified for clinging or scansorial in the body louse, the tibia being stout and bearing at one end a thumb-like process with a distal spine. The thumb is apposed to the single tarsal segment and a curved pretarsal claw. While grasping the body, the tarsus and pretarsus work against the thumb. The hindlegs are again adapted for swimming or natatorial habit in aquatic beetles like *Gyrinus* and *Dytiscus*, where the femur, tibia and the first foretarsal segment are broad and flat with dense, flat setae serving as oars. The forelegs are modified for digging in the nymph of Cicada, the femur being enlarged and very stout and provided with strong sclerotised spines. The forelimbs are also adapted for the fossorial habit in *Gryllotalpa* which has a very stout femur, a short stout tibia and the tarsus bearing strong cutting shears, or tooth-like lobes for cutting the roots. In several insects, legs are modified to hold the females while mating, for example in the males of *Dytiscus* there is a sucker-like apparatus in the



▲ **Fig. 4.4** *Legs of insects—various types 1. Honey bee 2. Embiid 3. Hindleg of grasshopper 4. Foreleg of mantid 5. Hindleg of aquatic beetle 6. Body louse 7. Fossorial type in Gryllotalpa* fore tarsus. The first three tarsal segments are greatly expanded forming a flat disc with a number of suckers on the lower surface. The legs of the honeybee are adapted for many functions, there being the pollen comb on the inner surface of the first segment of the hind tarsus to remove the pollen from the body, the pollen basket or the corbiculae on the outer surfaces of the hind tibiae, the scraper or the spur on the apex of the middle tibia to scrape the pollen from the baskets, and the antennal comb on the front legs to remove the pollen from the antennae. In addition to these modifications, in many insects (e.g. Thysanoptera and Embioptera), there are special adaptations such as the presence of a protrusible vesicle or bladder in thrips which is extruded by blood pressure and helps the insect to walk on the surface. In embiids, the first tarsal segment of the forelegs becomes greatly inflated by the presence of silk glands used in the construction of silken tunnels within which the insects live. The typical walking legs or ambulatorial legs have the basic pattern of structure.

The Wings of Insects

The wings of adult insects are articulated to the sides of the meso- and metathoracic terga by a complex group of sclerites (Fig. 4.7). There are normally two pairs of wings, the fore wings and the hind wings but in Diptera there is only one pair, the hind wings being reduced to small stems, the halteres. While the Apterygota are wingless there are several adult pterygotes without wings as in termites, lice, and fleas. Regarding the origin of wings the following three theories have been postulated:



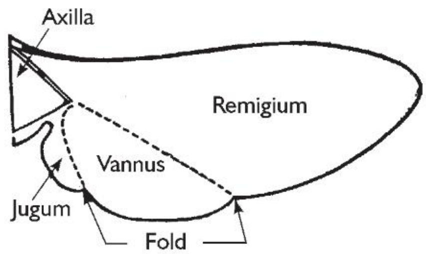
▲ **Fig. 4.5** *Wing sectioned at a vein (R.F. Chapman, 1969)*

1. The flying fish hypothesis of Oken (1831) who considered the wings to be homologous with the nymphal abdominal gills of some aquatic ancestors and as seen in some modern ephemerids.

2. The hypothesis of Muller (1873) postulating that wings arose from lateral tergal expansions or the paranotal lobes of the thorax. These paranotal lobes were very characteristic of the prothoracic terga of fossil insects, which had in addition, two pairs of well developed, almost identical wings. Because of this it is presumed that the immediate ancestors of winged insects had such paranotal expansions, probably serving as gliding organs. The notum is also produced laterally in cockroaches. The development of sufficient flexibility at the base of each paranotal lobe, perhaps led to the evolution of these lobes into the organs of flight.

3. Wigglesworth (1965)* has suggested that the wings arose in tiny, passively air-borne insects and the presence of light cuticular thoracic expansions facilitate take off. The development of muscles helping their twisting, also would afford control while landing. The next step in efficiency would be the appearance of flapping muscles, increasing take off and landing efficiencies. This new hypothesis, therefore, precludes the possibility of the ancestral winged insect being a tiny species. A more plausible theory explained by *Alexander and Brown* (1963) implicates mating behaviour in the elaboration of insect wings.

The typical pterygote wing is a flattened, double-layered expansion of the body wall, with a dorsal lamina and a ventral lamina, having the same structure as the integument (Fig. 4.6). According to the mode of development of the wings, the pterygotes are subdivided into the exopterygota, with the wings directly arising as hollow, flattened outgrowths of the body wall and gradually increasing in size with each moult, and the endopterygota where they develop usually within pouches of the epidermis and these wing buds become subsequently everted before becoming the adult. This early development is concealed within the pouches. The fundamental plan of development of both exopterygote and endopterygotes is similar. The dorsal and ventral laminae or the upper and lower layers of the epidermis grow, meet and fuse, except along certain lines. The spaces or lacunae left open serve for the passage of tracheae, nerves and the circulating blood. In subsequent stages of development, the walls of these channels become thickened and these cuticular walls constitute the walls of the wing veins. With the completion of development, the epithelial cells die, leaving the adult wing as an entirely cuticular structure, nourished by blood circulating through the veins.



▲ **Fig. 4.6** *Parts and folds of wing (Snodgrass, 1935)*

A generalised pterygote wing is more or less flattened or triangular, with an anterior notal margin, a distal margin, and a posterior anal margin. The anterior area of the wing supported by veins is usually called remigium (Fig. 4.6), while the posterior area comparatively flexible, is termed the vannus. The two regions are separated by the vannal fold. The proximal part of the vannus is the jugum or jugal fold. The jugum when well developed is separated from the vannus by a jugal fold. The area containing the wing articula-

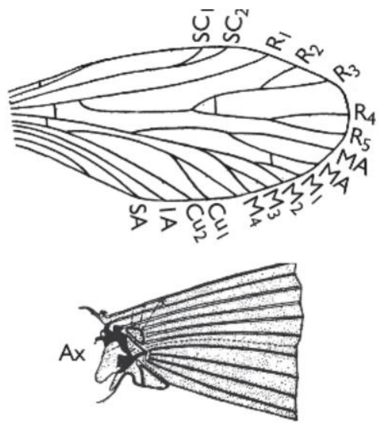
* *The Principles of Insects Physiology*, English Language Book Society and Mathew and Co. (Ltd.), UK

tion sclerite is termed as the axillary field. Sometimes at the posterior margin of the wing base there occurs additional membranous folds, the alula or calyptus.

The wings may be delicate and membranous, or as in the Orthoptera, the forewings may become leathery to protect the hind wings and are called the tegmina. In the Hemiptera, the wings may be half leathery from the basal half and half membranous in the distal half when they are termed the hemelytra. In the Coleoptera, the forewings become highly sclerotised and are called the elytra.

Wing Venation

Venation is the term given to the arrangement of the veins on the wing. It is of importance in the taxonomy of insects as the pattern of variation is constant for each species group. It would, therefore, be useful to describe the generalised type of wing venation to understand the deviation from the basic pattern. Such a basic pattern has been designated the archetype venation (Fig. 4.7). The system of tracheae found in the developing wing normally indicates the broad nature of the subsequent venation. Commencing from the anterior margin, the arrangement of the principal veins in such a hypothetical wing venation is as follows.



▲ **Fig. 4.7** *Wing showing archetype venation and base of wing inter-articulating axillary sclerites (shown in black) (Snodgrass,1935)*

The first vein (Fig. 4.7) is the costa *(C)*, an unbranched vein forming the wing or costal margin. Lying closely behind it is the subcosta *(Sc),* also usually undivided. The subcosta is followed by the radius *(R)* which divides into an anterior branch R_1, and a posterior branch, the radial sector *(Rs),* which in turn divides into four branches R_2, R_3, R_4, and R_5). The median *(M)* is the fourth vein and is typically into two, branched with an anterior median *(Ma)* and a posterior median *(Mp)*. The posterior median vein is branched into four, (Mp_1–Mp_4). The median anterior is seldom present, so that it is usual to label the branches of the median posterior as M_1–M_4. The fifth vein is the cubitus, which is also divided into the anterior cubitus (Cu_1) and a posterior cubitus (Cu_2). The anterior cubitus is forked into two branches (Cu_{1a} and Cu_{1b}). Behind the cubitus are varying number of unbranched anal veins or vannal veins. According to Snodgrass, the first anal vein *(la)* does not belong to the same series as the others and is designated 'post-cubitus'.

In order to provide rigidity, a system of cross-veins between the veins is developed. In Orthoptera and Odonata, the cross-veins are so numerous that there is a close network of branching veins and cross-veins. But in many insects there is a definite number of cross-veins, with specific positions and designations. The humeral cross-vein *(H)* lies between the costa and the subcosta; the radial cross-veins *(R)* between R_1 and the first four of *Rs*; between the two forks of *Rs* is the sectorial cross-vein *(S)*; the median cross-vein *(M–M)* is between the second and the third media M_2 and M_3; and between the media and cubitus are the mediocubital veins *(M–Cu)*. The cross-veins result in the wing surface being divided into a number of areas called cells bound by veins. From this archetype venation further specialisation results as in the Odonata and Neuroptera by addition to the number of existing branches or by reduction owing to the loss of veins due to secondary fusion of veins as in many Hymenoptera and Diptera. According to whether the veins fold upwards or downwards they are called convex or concave veins, but this does not appear to be consistent.

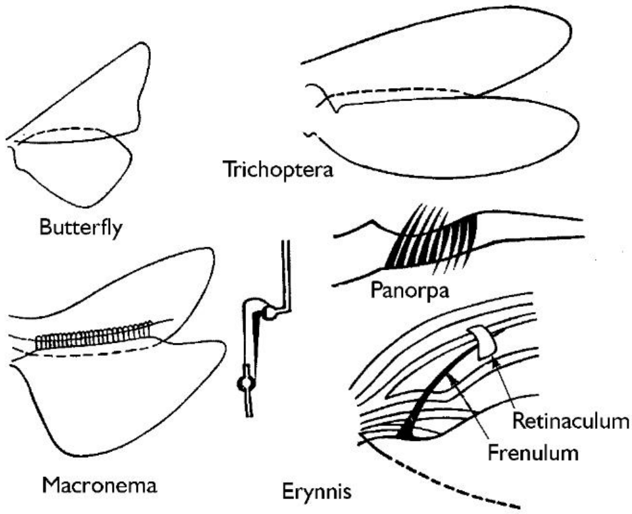
Wing Articulation

Associated with the base of the wing are a number of sclerites serving both as levers and for muscle attachment. The notal and the pleural wing processes—the basalar and subalar plates—previously mentioned in the thoracic terga, are some of the sclerites. Further, each wing is attached to the body by a membranous area containing a number of small articular sclerites, collectively called the pteralia. These include an anterior humeral plate at the base of the costal vein, and associated with the subcostal, radial veins are a group of axillaries, and lying at the base of the medio-cubital area is a pair of median plates. The axillaries are generally three in number, sometimes with a fourth one added. The first axillary is associated with the anterior notal process at the lateral edge of the scutum. Its anterior end is slightly produced to be attached to the base of the subcosta. The second axillary sclerite articulates on the one hand with the first axillary and on the other to the base of the radial vein. The third axillary lies in the posterior region of the articular area of the wing. Anteriorly it articulates with the posterior end of the second axillary and posteriorly with the posterior notal process of the tergum. Whenever the fourth axillary is present it is a small plate lying between the third axillary and the posterior notal processes. The median plates, two in number, lie lateral to the second axillary and anterior to the third. The proximal median plate is the anterior median plate and is attached to the third axillary while the dorsal or the posterior median plate is associated with the base of the medio-cubitus. Of the pteralia, the second axillary plays the role of a pivotal sclerite of the wing base, while on the third axillary, the flexor muscles are inserted and is concerned with the flexor mechanism of the wing, along with the two median plates.

The wing hinge and some other places of wing base show elasticity which has been attributed to the rubber-like resilin. Resilin is recognised as an elastic material from which insectan epidermis constructs versatile mechanical springs. This material is capable of a wide range of deformability and recovery.

Wing Coupling Mechanisms

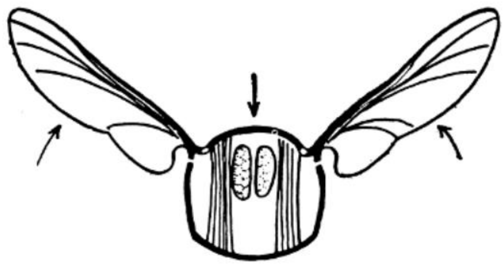
In primitive insects the two wings probably moved independently, but in all modern pterygotes there is an excellent coordination for moving the two wings as a whole. Several adaptations or mechanisms exist to achieve this condition (Fig. 4.8). In some Lepidoptera, finger-like processes of the jugum of the forewing clasps the hindwing in flight. In many moths, the hindwings may bear at their costal margins near base, the frenulum consisting of a tuft of bristles or a stout bristle which fits into a retinaculum in the forewings. In the honeybee, the hindwings may bear the hamuli consisting of a row of hooks on their costal margins fitting into the incurved posterior margin of the forewings. And in some butterflies, synchronous movements of the two wings are ensured by the great expansion of the proximal part of the costal margin of the hind wings which extends beneath the forewings. The wing muscles also play a great part in the synchronous movements of the wings.



▲ **Fig. 4.8** *Wing coupling mechanisms (adapted from R.M Fox & J.W. Fox, Introduction to Comparative Entomology, Reinhold Publications Corp.)*

Wing Movements

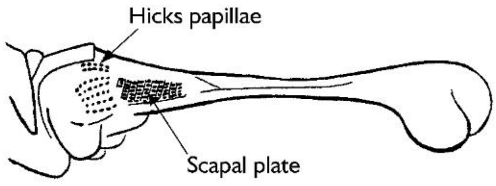
In the majority of insects, paired sets of muscles are present in the mesothorax and metathorax, which help in the movements of the wings. Some of the more important muscles are the dorsal longitudinal muscles which act as the principal depressors of the wings; the tergosternal muscles lying at the sides of the dorsal muscles in the anterior part of the segment, serving to elevate the wings; and the axillary muscles attached directly to the wing bases, arising on the pleuron and inserted on to the first three axillaries serving for wing flexion. As the wing is directly hinged to the tergum by the first two axillaries, the wing is capable of up and down movement involving up and down strokes and partial rotation as well as limited movements of flexion, involved in folding the wings after flight or extending it before flight. So during flight a contraction of the dorsoventral or tergosternal muscles lowers the tergum and elevates the wings (Fig. 4.9), while contraction of the dorsal longitudinal muscles raises the tergum and lowers the wings.



▲ **Fig. 4.9** *Raising of wing by lowering tergum (Snodgrass, 1935)*

Sense Organs involved in Wing Movements

Sensory setae functioning as mechanical sense rods probably respond to air flow over the wings. At the base of the wings are specialised sensillae arranged in groups in blattids, acridids, etc., which are described to be sensitive to distortions of the base of the wings in specific planes. Where the insect possesses ability to manoeuvre well, the sensillae are more numerous. Stretch receptors are also known to help the control of wing movements in some insects. In adult Diptera, the hindwings form the halteres (Fig. 4.10). Each is a slender rod, clubbed at the free end and enlarged at the bases. On this basal part are two large groups of sensory bodies (campaniform sensilla) forming the smaller set of Hick's papillae and the larger set of the scapal plate. The organ is helpful in maintaining stability in flight.

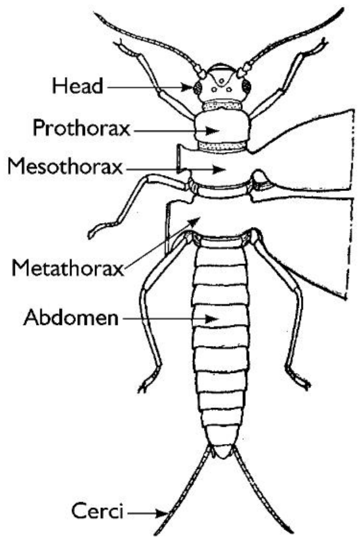


▲ **Fig. 4.10** *Haltere showing sensoria—dorsal aspect (R.F. Chapman, 1969)*

◆ Chapter 5

The Abdomen

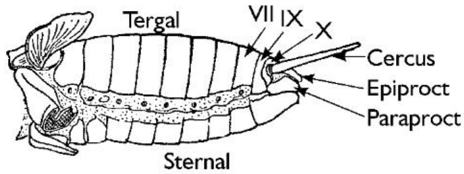
The number of primitive segments in the abdomen of all insects, as shown by embryological studies, is 11 alongwith a small terminal telson. However, in Protura and Collembola the number of segments is much less. Within the Protura a tendency for addition of segments during development is seen—a phenomenon called anamorphosis. On the contrary, the Collembola posses only six segments in all stages. Among the living insects, only the Protura retains a distinct telson. Though 11 segments are recognised in the Thysanura, there is a tendency for a general reduction in the number of segments by coalescence or loss at the posterior end (Fig. 5.1). In some insects, as in the Orthoptera, the 11th segment may persist as a dorsal plate, the epiproct, and two lateroventral plates, the paraprocts. In some, the 10th segment may also disappear. In many specialised pterygotes some of the proximal segments may be reduced. The eighth and ninth segments in the female and the ninth in the male are generally referred to as the composite genital segments. The segments preced-



▲ **Fig. 5.1** *Tagmata of adult insect (Snodgrass, 1935)* ing these are the pregenital or the visceral segments. These have the same generalised structure as the other regions of the body, with a dorsal tergite, ventral sternum and lateral unsclerotised pleurons in between.

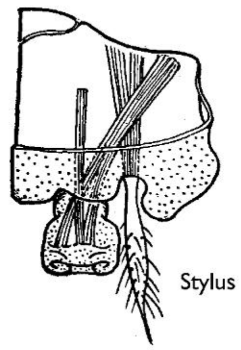
Each abdominal segment in some insects like Thysanura bears a pair of appendages which may be retained in its entirety or in a reduced state in the adult. These appendages are the coxites or plate-like limb bases, each carrying a style. Some retain the style, the coxites being fused with the sternum. Fleshy, leg-like processes, the prolegs, are characteristic of abdominal segment nos. 3–6 and no. 10 of most caterpillars. However, no appendages exist on pregenital segments in adult pterygotes. The external genitalia and the terminal long and segmented cerci of the 11^{th} segment are the appendages of the genital segment. The cerci may be variously modified being long, thin and filamentous as in Thysanura and Ephemeroptera where, in addition, there is a median caudal filament arising as an extension of the epiproct; and forceps or pincer-like as in earwigs.

As has been mentioned earlier, the abdomen comprises the dorsal tergal, ventral sternal and the lateral pleural sclerites (Fig. 5.2). In addition, lateral tergal sclerites or latero-tergites may be present, when dorsal tergite is termed the median tergite. Similarly, small sclerites occur in the pleural region and appear to be lateral subdivisions of the pleuro-sternal regions and called the latero-sternites. Actually they are pleurites since they lie in the pleural region. The sternum in the Thysanura bears stylus-bearing plates and when the sternal plates include the limb bases or coxites, it is usually designated coxosternum.



▲ **Fig. 5.2** *Abdominal segments (ibid)*

Abdominal appendages of various kinds occur in the adults of more primitive insects like the Protura, Thysanura, and Collembola as well as in many pterygote larvae (Fig. 5.3). While the commonly seen appendages are the gonopods of the genital segments and the styli of the 11^{th} segment, in the Protura we come across a pair of short cylindrical appendages on each of the first three abdominal segments, terminating in eversible vesicles. In Collembola are present very characteristic appendages, the ventral tube or

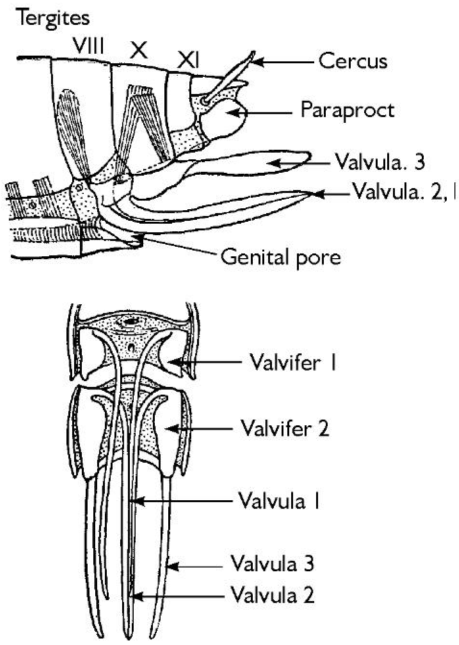


▲ **Fig. 5.3** *Abdominal appendage of Thysanura (ibid)* collophore carried on the first abdominal segment, the clasp or retinaculum or hamula on the third abdominal segment and the spring or furcula arising from the fifth abdominal segment. An adhesive function is suggested for the collophore, serving to hold the spring or furcula in place. The spring is the leaping organ, giving the name spring tails to Collembola. The thysanuran abdominal appendages are tapering processes or styli arising from flat basal lobes on the sterna. The abdominal appendages in the larvae of several aquatic pterygotes function as gills which take a variety of shapes. The prolegs of caterpillars have already been mentioned.

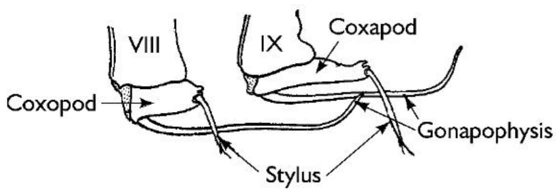
The External Genitalia

As was mentioned earlier, the ninth segment in the male and the eighth and ninth segments in the female are modified to form the genital apparatus. In all the females (Fig. 5.4 and Table 5.1) associated with the genital openings on the eighth segment is a structure serving for egg deposition and is called the ovipositor. It is formed of parts from the eighth and ninth segments. Though primarily used for oviposition, in insects living in surroundings such as soil or wood, it is also adapted for digging or boring. Using the terminology of Snodgrass, in all pterygotes the ovipositor is made up of three pairs of elongated sclerotised processes called the valvulae, each of which originates on a small sclerite or pleural plate, the valvifer. The first valvula is borne on the first valvifers arising on the eighth segment, while the second and third valvulae originate from a common basal sclerite, the second valvifer arising from the ninth segment.

In the apterygotes, as in Thysanura (Fig. 5.5), each coxopodite bears, in addition to the stylets, a slender process or gonapophysis. These four processes, the styli and the gonapophyses are clearly associated



▲ **Fig. 5.4** *Side and ventral view of tip of abdomen of female to show parts of the ovipositor (ibid)*



▲ **Fig. 5.5** *Ovipositor of Thysanura (ibid)* to form the ovipositor. As such it is presumed that the first valvifer of the pterygote ovipositor is the reduced coxopodite of the seventh segment and the first valvula, the gonapophysis being borne on the coxopodite. In insects like bees and wasps, the ovipositor is modified as a sting which normally is kept retracted in a sheath within the seventh abdominal segment.

Comparison of nomenclature proposed by Scudder and Snodgrass for the parts of ovipositor

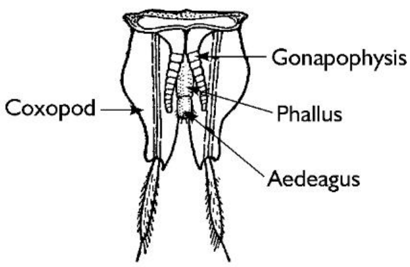
Table 5.1

Scudder, 1961	*Snodgrass, 1935*
First gonocoxa	First valvifer
First gonapophysis	First valvula gonapophysis
Second gonocoxa	Second valvifer
Second gonapophysis	Second valvula, gonapophysis

Scudder (1961), in his studies on the comparative morphology of insect ovipositor, points out that the ovipositor of the higher insects could be better interpreted taking the Lepismatidae as the basic type instead of the machilids as Snodgrass has done. He has proposed a new nomenclature for the parts of the ovipositor and includes two more sclerites—the gonangulum attached ventrally to the base of the first gonapophysis and articulated with the second gonocoxa and ninth tergite, and the gonoplac, the posterior outgrowth of the coxa of the abdominal segment no. 9, homologous with the third valvulae of Snodgrass.

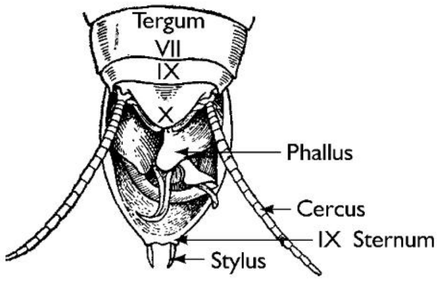
The Male Genitalia

The great structural diversity of the external genitalia of male insects (Figs 5.6, 5.7 and 5.8) has considerably strengthened the taxonomic studies in view of its value in correct determination of several species. As mentioned earlier, the male genital opening is placed on the posterior side of the ninth abdominal sternum. In the Collembola, however, they open on the fifth abdominal segment.

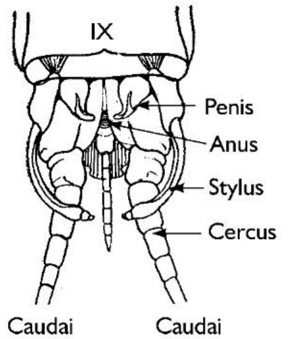


▲ **Fig. 5.6** *Thysanuran male genitalia, dorsal view (ibid)*

The majority of insects have a median genital opening at the extremity of the phallus or penis, the intromittent organ used in sperm transference to the female. In more primitive orders like ephemerids and some earwigs the opening of each genital duct is retained independently, resulting in two gonophores on paired penes. Lying on either side of the phallus are a pair of forceps-like structures, the parameres, which act as the principal genital claspers of the adult. Fundamentally, the genital structures arise from a pair of small ectodermal outgrowths close behind the ninth sternum. These are termed the primary phallic lobes. These grow and become elongated, so that the gonopores open at their ends in such insects as ephemerids where these primary lobes become a pair of penis. In the higher insects each primary phallic lobe divides into secondary lobes or phallomeres, the median pair termed mesomere and the lateral ones parameres. In most insects the mesomeres become hollow on their opposite surfaces and unite with each other to form the tubular median aedeagus. The cavity of the aedaegus communicates proximally with the gonopore. The opening at the distal end of the aedeagus is termed the phallotreme. While the aedeagus and parameres are normally constant parts of the male genitalia, sometimes one or the other may become absent or reduced or undergo secondary modification. The inner wall of the phallus is usually membranous and is termed as the endophallus. In some insects the base of the aedeagus is retracted into a pocket called the phallotheca. The male genitalia may also include other structures in addition to the penis and the claspers such as processes of various kinds borne on eighth or ninth posterior segments. These are collectively called the periphallic structures.



▲ **Fig. 5.7** *Ephemerid male genitalia, ventral view (ibid)*



▲ **Fig. 5.8** *Male genitalia of mantid, dorsal view (ibid)*

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Section Two

Physiology

◆ Chapter 6

The Digestive System

The organs concerned with the taking in of food, collectively termed the mouthparts, have been discussed in an earlier chapter. These mouthparts enclose a preoral cavity bound by the epipharyngeal wall of the labrum in front, the maxillae and the mandibles at the sides, and the labrum behind.

This cavity is partially divided into (a) an anterior cibarium provided with dilator muscles and partially sunk into the head and modified into a powerful sucking pump in Hemiptera, and (b) a posterior salivarium, which is hollow and pushing the posterior wall of the hypopharynx, on to which opens the common salivary duct.

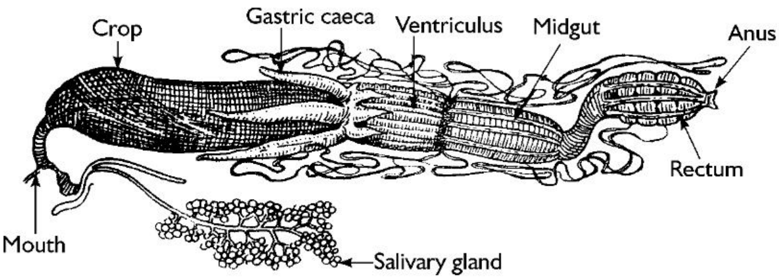
In order to inject the saliva into the plant or animal tissue, the salivarium is modified as the salivary syringe in most Hemiptera.

Salivary Glands

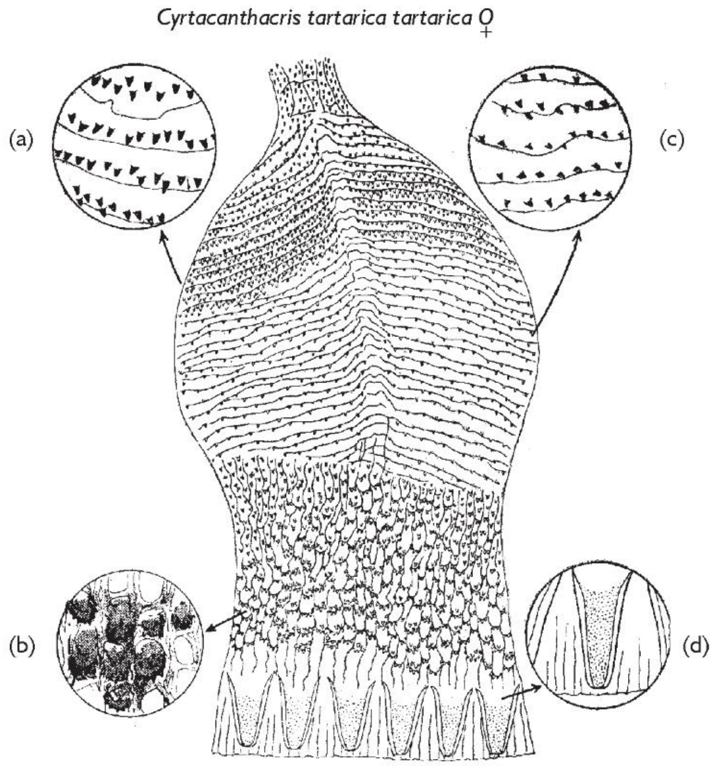
The salivary glands are usually paired tubular, racemose or branched structures with a number of lobes situated on either side of the foregut, generally in the thoracic region. The saliva secreted by these glands is often stored—as in the case of cockroaches, in reservoirs called salivary receptacles, whose ducts open by a common duct into the median salivary duct formed by the union of the salivary ducts of each gland. The salivary glands of the larvae of Lepidoptera and Hymenoptera are modified into silk-producing organs. In mosquitoes, bed bugs, etc, the saliva contains anticoagulant substances, while in some ants the saliva contains formic acid, and toxic substances in some others. Other well-defined glands also are present in many insects like mandibular glands, accessory labial glands, etc., which are modifications of glands associated with the gut.

Alimentary Canal

The alimentary canal comprises three distinct regions (Fig. 6.1), the foregut or stomodaeum, the midgut or mesenteron, and the hindgut or proctodaeum. The foregut and the hindguts possess a chitinous lining. A stomodaeal valve and a proctodaeal valve are generally present at the opening of the foregut into the midgut and that between the midgut and hindgut respectively. The true mouth is situated in the cibarium and leads into a comparatively narrow tube, the pharynx. The pharynx directly leads into the oesophagus, often enlarged posteriorly into a simple, sac-like crop which serves for food storage. The crop is not always present but when present may be only an enlargement of the oesophagus or a diverticulum from it. The crop is followed by a muscular proventriculus, often provided with strong cuticular plates or teeth serving for trituration and mixing of food (Fig. 6.2). The proventriculus is pushed into the cavity of the mesenteron to form the stomodaeal valve, generally consisting of four proventricular lips which serve to regulate the passage of food into the mesenteron preventing the regurgitation of food from the ventriculus to the crop. The foregut in grasshoppers or acridids is provided with numerous chitinised teeth arranged in various patterns. The mesenteron or the midgut is physiologically the most active part of the alimentary canal, being concerned with digestive function. Opening anteriorly into the midgut are usually a variable number of gastric caecae (Fig. 6.1), varying in number from two to six. Lying at the junction of the midgut and hindgut are the malpighian tubules discharging their products into the alimentary tract. The hindgut is usually differentiated into an anterior ileum and a posterior large intestine ending in an enlarged rectum.

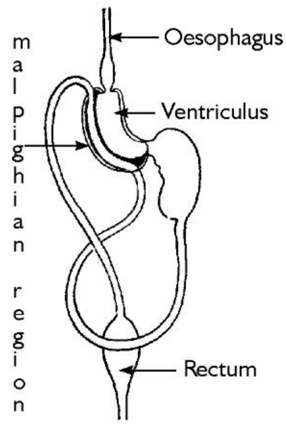


▲ **Fig. 6.1** *Alimentary canal of grasshopper (ibid)*



▲ **Fig. 6.2** *Foreget armature of Cyrtacanthacris (Courtesy : M.C. Muralirangan) (a) Left top: Chitinised ridges in the anterior region of crop with complex teeth arrangement. (b) Left bottom: Posterior region of the crop with vertical ridges and complex teeth arrangement. (c) Right top: Mid crop region with simple arrangement of teeth (d) Right bottom: Proventricular region without complex teeth arrangement.*

The alimentary canal undergoes variations in relation to the nature of the food and feeding habits, being short and straight in the more primitive insects. They dilate like the crop as in Orthoptera or the diverticula such as caecae, or become specially modified for the elimination of water and concentration of liquid food as in the filter chamber in Homoptera (Fig. 6.3). It may be just an association of the end of the midgut with the hindgut or may be come further complicated. In other words, the anterior region of the midgut is almost identical in structure to the posterior re-



▲ **Fig. 6.3** *Filter chamber of Homoptetra – simple type (Snodgrass, 1935)* gion and may even penetrate its walls, permitting water to be removed rapidly from the plant juices into the posterior regions of the gut, allowing the food material contained in the juices to be digested by the middle region of the midgut.

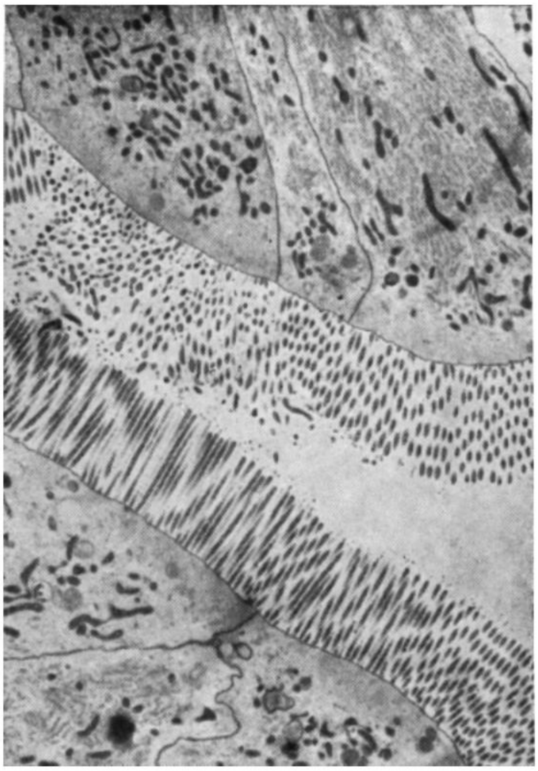
Variations of Alimentary Canal

Of the several structural types based on variation in the digestive tract, mention may be made of the following:

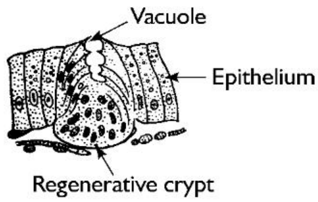
- Unspecialised condition as in caterpillars, where the foregut leads into the midgut and the hindgut.
- The foregut with a crop as in most Orthoptera.
- A diverticulum of the foregut for storage, but the midgut and hindgut are primitive as in adult Lepidoptera.
- The foregut with a specialised diverticulum for food storage as in blood sucking Diptera; the midgut more elongate and the hindgut with rectal glands.
- Highly specialised as in Homoptera, the midgut very long and in many the digestive tract adapted for the removal of excess water by the development of a filter chamber.

Histology of Alimentary Canal

Histologically, the foregut and the hindgut possess an inner chitinous lining or intima secreted by a layer of epithelial cells. The midgut epithelium presents a striking contrast because of the presence of secretory and regenerative cells. The layer of rather large epithelial cells is bound externally by the basement membrane, followed by the circular and longitudinal muscular layers. A characteristic feature of the epithelial cells is their striated border on their inner side (Fig. 6.4). The secretory cells of the midgut epithelium are often replaced by groups of regenerative cells or nidi (Fig. 6.5), whose number and frequency vary with insects. They may be absent as in the thrips or may be contained in depressions or crypts, either at their bottom or along the sides. Their function is replacement of the worn out or exhausted secretory cells. The mode of secretion also varies. For instance, it may be merocrine when the secretory products are discharged without any damage to the epithelium. The secretions accumulate at the free end of the cells to be discharged into the lumen. It may be holocrine involving disintegration of the secretory cells, i.e. the entire cell with its nucleus may disintegrate from the epithelium. The secretions usually appear as clear granules in the cytoplasm. Sometimes a continuous removal of the midgut epithelium occurs.



▲ **Fig. 6.4** *Electron micrograph of striated border of epithelial cells of midgut of cockroach. This region which appears striated under the light microscope shows microvilli under the electron microscope, X3700 (courtesy: N.R. Baker)*



▲ **Fig. 6.5** *Epithelial cells of midgut of larva of Dytiscus showing regenerative zone (Snodgrass, 1935)*

Extending from the midgut to the hindgut is a thin chitinous tube free from the epithelial wall which encloses the food within the midgut. This is the peritrophic membrane serving to protect the delicate epithelial cells from the coarse food particles. It may be a simple continuous structure produced by a secretion of a ring of cells at the junction of the foregut and hindgut, or formed by cells of the midgut secreting thin lamellae loosely attached to each other. This is an interesting example of a chitinous structure developed from the endoderm. The peritrophic membrane is lacking in fluid-feeding insects and dermestid larvae feeding on keratinaceous material like hair, feather, etc. When present, it generally serves a mechanical function, namely the prevention of the abrasion of the midgut epithelium from coarse food particles. The hindgut is similar in structure to the foregut, but with a thinner cuticular lining. Very characteristic of the rectum are the rectal pads, or papillae. There are six longitudinal bands of the cellular layer of the rectum and they play an important role in the maintenance of the proper water balance through absorption of water from the faeces.

One interesting modification of the alimentary tract is what occurs in adult mayflies. Here, the tract has been modified into an aerostatic system. The oesophagus is extremely narrow and the muscles of the gut can regulate air that is sucked in and retained in the tract. Stomach-like midgut has lost its glandular lining and behaves like a balloon. Its musculature also is scanty. lleum has developed a special air-letting valve.

The Physiology of Digestion

Insects possess a variety of digestive mechanisms to complement their feeding habits. The salivary glands secrete saliva containing many enzymes, but in bloodsucking insects like mosquitoes, the saliva has no enzyme, but has a substance preventing blood coagulation. In most insects amylase or invertase is found in the saliva but in some cases protease may also be found as in omnivorous insects like cockroaches. A variety of enzymes will be present in accordance with their diet and these include protease, lipase, amylase, invertase, etc. The proteases are the dominant enzymes in the carnivorous insects. Interesting examples of extra-intestinal digestion occurs in insects by means of proteolytic enzymes of the saliva. As a result of this, partial digestion may take place before food is ingested. Typical examples are the flesh-fly larvae which pour out proteolytic enzymes on to their food. Some plant lice also inject amylase into the tissues of the plants where starch digestion occurs. In general, the digestive juices of insects are weakly acidic or alkaline, though in the larvae of some Lepidoptera and Trichoptera the contents of the midgut are always strongly alkaline. On the other hand, the tendency towards a more acidic nature occurs in the crops of many orthopterans.

The pH of the gut increases in alkalinity along its length. In some cases as in *Locusta,* the pH of the midgut is more acidic during passage of food, but later the alkalinity increases. In general in the examples studied the range of pH in the foregut is 5-6.4, the midgut 5.6–7.2, and the hindgut 5.9–7.5. Some insects living in rotten wood or vegetation possess a fermentation chamber in their hindgut harbouring bacteria that can break down cellulose or as in the case of some cockroaches they are contained in the crop.

Some of the well defined enzymes studied in insects are:

salivary gland	—amylase (rarely protease)
foregut	—amylase, maltase, invertase (rarely protease and lipase)
gastric caecae	—maltase, invertase, lipase, protease
midgut	—maltase, invertase, lipase, protease
hindgut	—amylase, maltase, invertase, lipase, protease

Intestinal flagellates (trichonymphids) are present in large numbers in the enlarged hindgut of wood-feeding termites and which help in the digestion of cellulose. It is also interesting to observe that some ants and termites and bark beetles depend on fungi for transforming the wood into a digestible form by growing fungus gardens.

◆ Chapter 7

Nutrition in Insects

Nutritional requirements are the food requirements of an insect. A study of nutrition in insects will give a clear understanding of the growth and methods of culture of the organism. Two essential regions where nutrients are stored are in the egg as the yolk and the fat bodies of the larval, pupal and adult stages. The nutrients in the egg form the material for embryonic growth, and the fat body nutrients are the storage depots.

The nutritional requirements of an insect are obtained chiefly from the diet. These comprise carbohydrates, amino acids, lipids, vitamins, and inorganic salts.

Carbohydrate

Plant starch yields the carbohydrates in general for energy release. In fluid feeders, sucking in blood, sap, nectar, etc., various sugars are also imbibed as food. The carbohydrates are converted into simple sugars like dextrin, fructose, glucose, maltose, sucrose, sorbose, trehalose, etc. Glucose and fructose are well utilised, pentose sugars are not used at all.

Amino Acids

Amino acids are needed for production of tissues and enzymes. The food contains the bulk of proteins needed by the insect. Ten of the 21 amino acids are essential for growth; they are arginine, lysine, leucine, isoleucine, tryptophan, histidine, phenylalanine, methionin, valine, and threonine. The balance between the amino acids is important in nutrition.

Lipids

Lipids or fats in the insects are the chief storage centres of energy. In sustained flight, fat is the main fuel (in *Schistocerca, Apis*, etc.) and such continued flight shows remarkable endurance of one to three days as in migrating forms. They, however, are not very essential dietary constituents because the insects possess the ability to synthesise them. In plant feeders only small quantities go in along with food. All insects need a dietary source of sterol for growth and reproduction. Phytophagous insects use plant sterols (Lepidoptera, beetles) but animal feeders get them rather directly from food. Cholesterol storage is seen in insects like *Tenebrio.* Linoleic acid is required in caterpillars for normal growth.

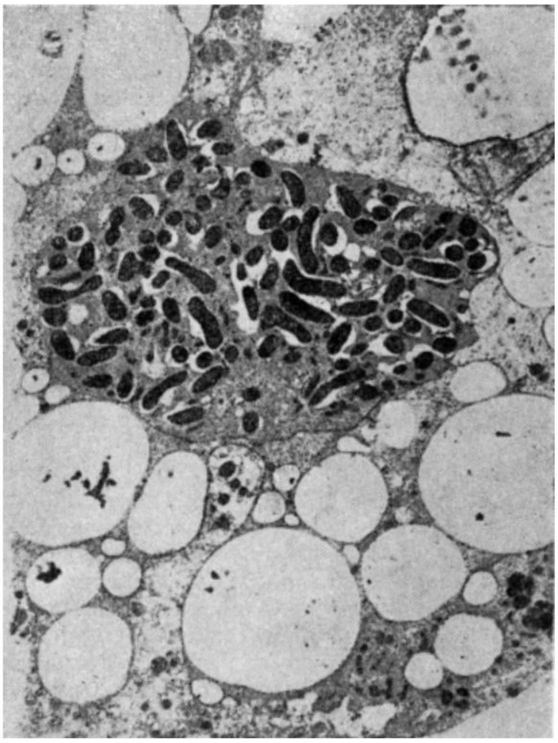
Vitamins

Provitamin A (b-carotene) is important for *Schistocerca* for normal rate of growth and moulting, but in many insects it is not an essential dietary requirement. As the visual pigment retinene is derived from carotenoids, small amounts of this will be necessary in all insects. The vitamins of the B group (thiamine, riboflavin, nicotinic acid, pyriodoxine, and pantothenic acid) are necessary for all insects. Though not essential to promote growth, inositol is necessary in *Ephestia* and lipoic acid in Diptera. Large quantities of choline are needed in *Schistocerca*, *Achaeta* and *Blattella.* Symbionts which are mutualistic and living in the tissues provide provitamins in the beetle *Stegobium.* Vitamin C though present in several insects is not an important dietary element. In insects like *Schistocerca*, absence of vitamin C results in abortive ecdysis and death.

Nucleic acids added in food will improve growth in *Drosophila*, but are not a necessary factor needed in insect dietary. No specific detailed study has been made on the inorganic salt requirements of insects. To provide ionic balance in activities of living cells, these are necessary. Iron, copper, iodine, manganese, cobalt, zinc and nickel are described as essential trace elements.

Nutritional factors when not present adequately will disturb growth, moulting, and reproduction. The form and colouration of insects like *Schistocerca* are also affected by such deficiencies. In social insects, especially *Apis*, dietary differences are intimately involved in polymorphism, as in determination of queens.

Microorganisms are constantly associated with insects that have a restricted diet–as in bloodsucking lice, nycteribids, some tabanids, cockroaches, termites and ants. The microorganisms are intracellular (Fig. 7.1), and the cells containing them are the mycetocytes. The microorganisms may be bacterioids as in cockroaches, or flagellates as in termites. These are essential for digestion of specialised food material like cellulose in termites or for synthesis of B-vitamins as in cockroaches. Methods have been devised to ensure transmission of these microorganisms to the offspring by moving into or on to the eggs that are produced by the host. Bostrychid beetles transfer the symbionts via the semen.



▲ **Fig. 7.1** *Section through the fat body of the cockroach to show mycetome. x2330; shows the mycetocyte in the center with microorganisms*

◆ Chapter 8

Fat Body

The fat body of insects is in the form of loose masses of cells which are mesodermal in origin. Membraneous connective tissue sacs enclose these cell clusters. They look like aggregates of blood cells. They freely project into the haemocoele and are penetrated by a dense network of fine tracheoles.

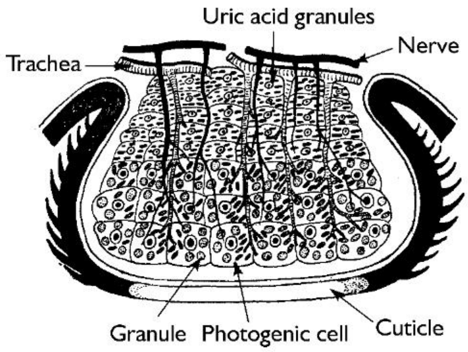
The major part of the fat body is built up of cells called trophocytes. In the young animal the trophocyte is small, comparatively clear and with large, rounded nucleus. In due course, the cell develops cytoplasmic vacuoles and becomes enlarged due to deposits of glycogen, fats, or protein. At metamorphosis, albuminoid granules appear in the cytoplasm and these sites are described to be definite organelles concerned with synthesis of lipids in *Anthrenus*. Droplets of the enzyme lipase are associated with each droplet of fat.

The trophocytes get loose and float about like haemocytes in *Aleyrodes* and in aquatic bugs blood cells contribute to the formation of trophocytes. It is possible that there is a relationship between trophocytes and haemocytes.

Functionally, trophocytes are store houses of food material. Fat is the chief component. Glycogen and protein also are stored in them. Protein storage is marked in animals which hibernate. Nearly 33% of the weight of a mature *Apis* larva is due to trophocytes. The reserves in trophocytes are drawn up under conditions of starvation or inactivity. They contribute also to the development of eggs. The presence of lipase in fat droplets within cells indicate that hydrolysis into fatty acids and glycerol also occurs within this organ. They then get transported to respiring tissues for utilisation.

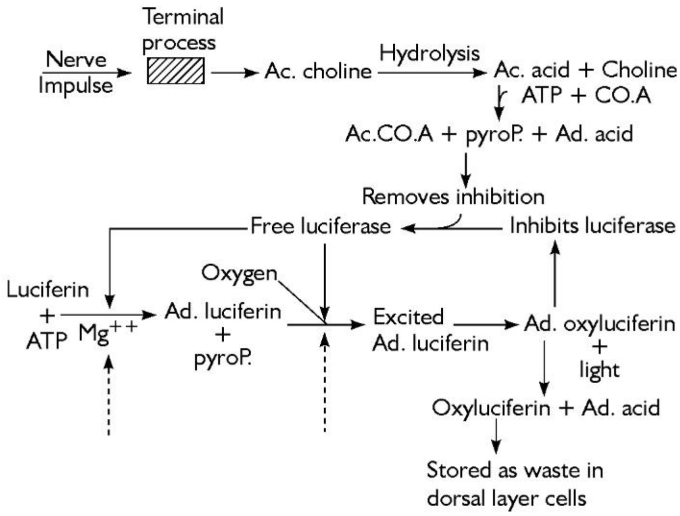
Uric acid is accumulated in cells called urate cells which lie scattered among trophocytes in insects like *Blatta*, Collembola, etc. It is suggested that these cells act as stores or reserves of nitrogen to be used in production of new tissues by their breakdown.

Mycetocytes are scattered inside the fat bodies in cockroaches (see Fig. 7.1). In *Kalotermes* the fat bodies differ in structure and chemistry in that they have come to be the organs of protein synthesis.The fat body cells constitute the photogenic tissue in Collembola. Many insects are capable of producing light and it is believed that the bodies have become modified as light emitting (photogenic) organs. A transparent cuticle covers the surface and a reflector layer is formed at the base of the photogenic organ (Fig. 8.1) The reflector is with white granules of uric acid. This is the case in glow worms (*Lamprophorus*). Sometimes bacterioids or bacterioid-like bodies form the granules as in *Photinus.* The photogenic cells contain a substance known as luciferin, which gets oxidised by an enzyme luciferase to emit light. ATP reacts with luciferin yielding a substance called adenyl-luciferin and pyrophosphate. Magnesium or manganese salts are also needed Oxidation of adenyl-luciferin produces light. This is mediated by luciferase, which also catalyses the reaction with ATP (Fig. 8.2). Luciferin is synthesised in fireflies and it has also been isolated from them.



▲ **Fig. 8.1** *Section through photogenic organ (diagrammatic)*

The light emitted may vary in tint as in *Pyrophorus* in which the two thoracic organs show greenish light, and the abdominal ones show orange light. The railroad worm of America *Phryxothrix* emits red light at the head end and segmental rows of greenish yellow light on the abdomen. The wavelength of the light emitted is variable, in *Photinus* it is 520–650 mμ, in *Lampyris* it is 518–656 mμ, and in *Pyrophorus* it is 486–720 mμ. Many Asian species flash in unison. In some, at least the emission of light is a mating signal, as in *Lampyris*, where the wingless female attracts the flying male by her glow. In *Photinus* both sexes can emit flashes. If another insect flashes two seconds after a male's signal, the latter will turn and proceed to the responding insect.



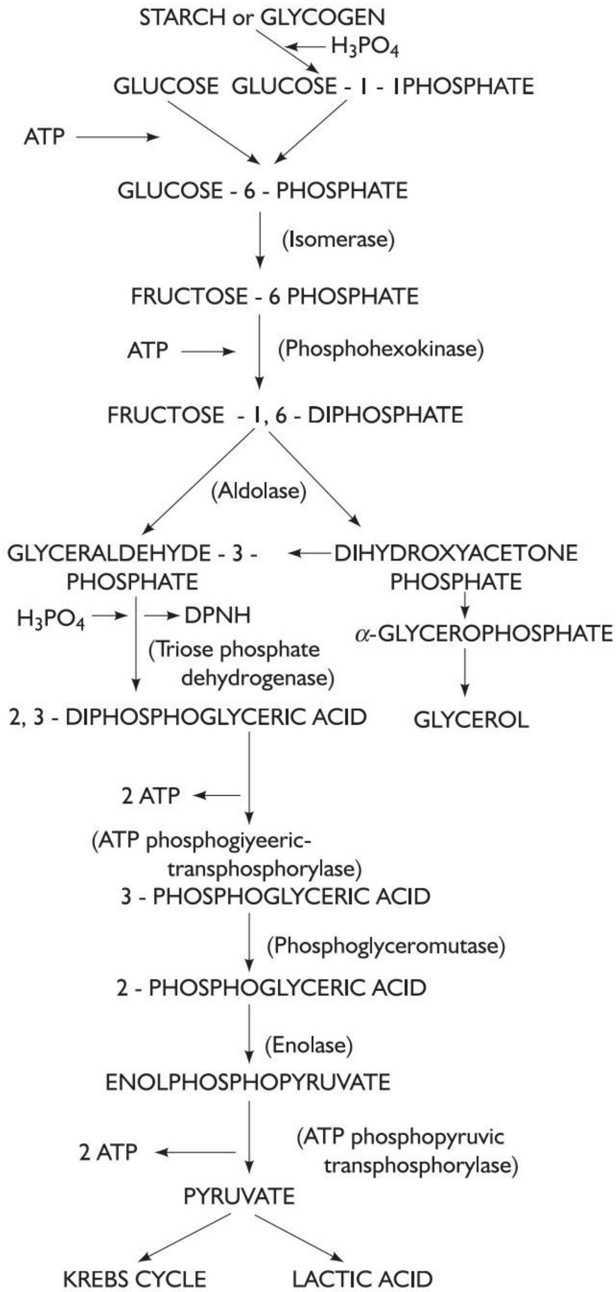
▲ **Fig. 8.2** *Scheme of reactions in photogenic process. (R.F. Chapman, 1969).*

◆ Chapter 9

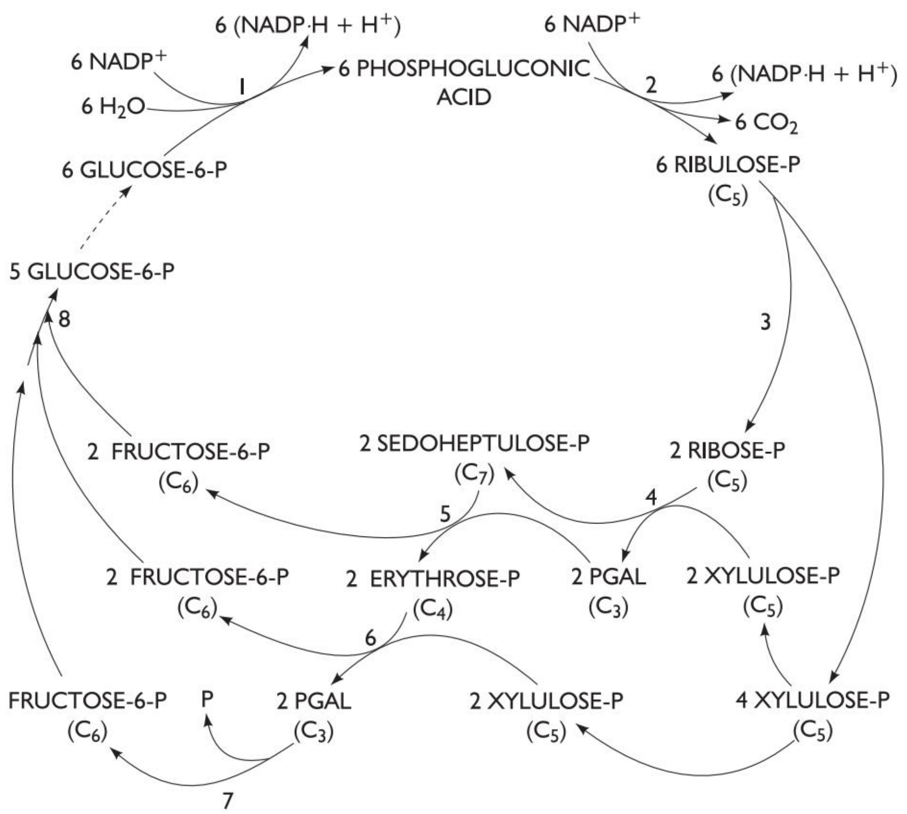
Intermediary Metabolism

Metabolism is a term meant to denote all the biochemical processes that occur in animals, resulting in the production of energy, and waste products, rendering the latter harmless. Intermediate (intermediary) metabolism refers to metabolic processes that are not immediately concerned with energy release, but refers to the events that occur between the assimilated energy source and the release of energy. The fundamental processes are cellular. Metabolic processes show variations in their rate depending on the stage (larva, adult) and activities. External factors like temperature also influence the rate. Metabolic control has been attributed to hormonal and neural mechanisms. These cellular phenomena occur in living cells on a general pattern and details of these will be available in books on cell physiology or comparative physiology.

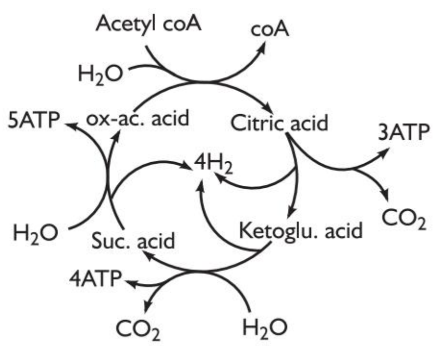
The constituents of food which will be available to the insect may be characterised as carbohydrates, lipids, and proteins. Carbohydrates are broken up into a simple sugar, usually glucose. Three pathways are common for energy release from glucose, viz. Embden-Meyerhoff pathway, the pentose pathway (hexose monophosphate shunt), and the cycle of Krebs (citric acid cycle or monocarboxylic acid cycle.). The latter is aerobic and completes the degradation of sugars, besides proteins and lipids. The three pathways of breakdown and the enzymes responsible for the activities are indicated in Figs 9.1, 9.2 and 9.3.



▲ **Fig. 9.1** *Embden-Meyerhoff pathway (R.L. Patton, 'Introductory Insect Physiology', Saunders Co.)*



▲ **Fig. 9.2** *Hexose monophosphate shunt (McGraw-Hill Pub. Co., New York)*

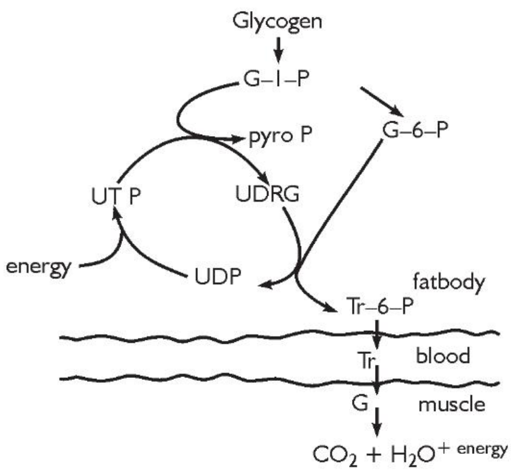


▲ **Fig. 9.3** *Krebs cycle (Weisz, The Science of Biology, McGraw-Hill Pub. Co., New York)*

Studies have shown that all pathways studied in mammals occur in insects also. Within the cell the mitochondria form the organelles playing a key role in these phenomena. All the enzymes of the Krebs cycle occur in the mitochondria of insects and the complete oxidation to pyruvate has been established.

Carbohydrate Metabolism

In insects glycogen exists in cells and tissues and trehalose, a disaccharide, occurs in the haemolymph. Both these are the sources of glucose. Trehalose supplies energy in flight, during starvation, and metamorphosis. The metabolic pathways are shown in Fig. 9.4. Trehalose is hydrolysed by the enzyme trehalose to yield glucose and the enzyme occurs in blood, gut, and fat bodies. Ordinarily fat bodies contain stores of trehalose. Glycogen is stored in tissues like fat body, muscles, midgut cells, etc. Glycogen yields energy after conversion into glucose. In forms like the larva of *Aedes*, amino acids have been seen to yield glycogen. Chitin, a chief cuticular constituent is formed from carbohydrate reserves, of which trehalose is important. Most of the cuticular material is reabsorbed after digestion by the ecdysial fluid.

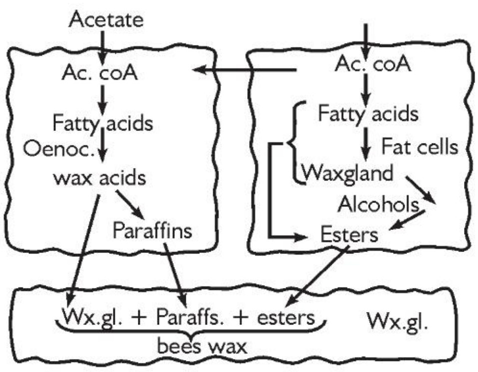


▲ **Fig. 9.4** *Pathway of synthesis of trehalose (redrawn from R.F. Chapman, 1969)*

Lipids

These include neutral fats (triglycerides), phosphatides, cerebrosides, fat soluble vitamins, and steroids. They comprise the major food reserves of insects. The fatty acids are synthesised in the fat bodies and in other tissues from amino acids, sugars, and simpler fatty acids. The enzyme lipase is highly active in the fat body; glycerol is produced and then phosphorylated to glycerophosphate. These are moved into the flight muscles.

The cuticular water-proofing is afforded by a thin layer of wax. Shellac produced by *Kerria*, plates of wax of scale insects, and comb material of bees are all constructed of wax. Composition of these waxes varies. For example in beeswax, 12% is paraffin, 72% esters, and 13% free long chain acids. Cells of fat body and oenocytes help in its (Fig. 9.5) synthesis in honeybees, getting extruded as flakes from abdominal wax glands. It is also known that oenocytes play a part in the formation of the cuticle. Steroids are fat-like compounds which do not form esters or saponify. They have a characteristic structure, the rings always having at least one OH group. Cholesterol occurs in insects, and sterols are all converted into cholesterol. For normal life an insect requires steroids as a dietary material. Insect moulting hormones are steroids. Various lipid derivatives are also known to carry out specific functions. To this category belong pheromones, royal jelly of honeybees, etc.

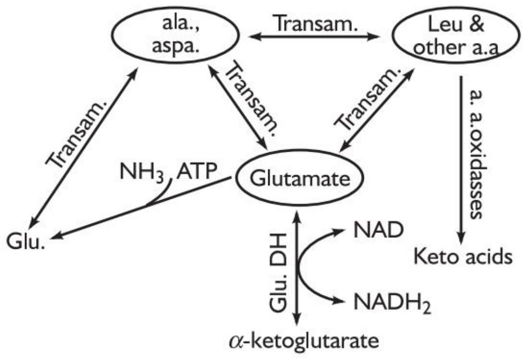


▲ **Fig. 9.5** *Pathway of synthesis of wax (ibid)*

Protein

The simpler substances of proteins called amino acids occur as free amino acids in blood and the concentration of these in haemolymph is high. The free amino acids give rise to compounds like butyric acid, ornithine and taurine. A number of amino acids like glutamate, proline, aspartate and alanine are synthesised in the fat body. The transfer of amino groups from an amino acid to a keto acid without the production of ammonia is known as transamination. In *Bombyx* 19 amino acids function as donors in transamination. Malpighian tubules show the greatest transaminase activity. Glutamate plays a major role in the transfer of nitrogen from one compound to another (Fig. 9.6). This central role aids in incorporating and distributing nitrogen.

Body proteins get synthesised from amino acids. RNA acts as a template for protein synthesis. Functionally proteins form essential components of cells, secretions, blood proteins, materials like silk, etc.



▲ **Fig. 9.6** *Reactions of amino acids in insects (ibid)*

Catabolism

The end products in carbohydrate and lipid metabolism are water and carbon dioxide. They escape along with urine and through the tracheal system. Catabolism of proteins produces ammonia in addition. Being toxic, ammonia gets usually converted into uric acid which is less harmful and needs less water for eliminating it.

Urea arises directly from amino acids by deamination or by action of urease on urea. *Tenebrio*, living in a dry habitat, shows both uric acid and urea. Fluid feeders like *Apis* produce comparatively more ammonia. Urea is the end product of mammalian catabolism and arises through the ornithine cycle, a process poorly understood in insects. Blood feeders like *Rhodnius* derive urea directly from the food.

Uric acid is formed from utilisation of glycine, glutamine, etc. in the fat body, and also from the catabolism of nucleic acids. Adenine and guanine released from the breakdown of nucleic acids give rise to uric acid.

Adenine→Hypoxanthine→Xanthine→Uric acid→Guanine→Xanthine→Uric acid

Allantoin is excreted by aquatic insects, and in Diptera, Coleoptera, and Orthoptera, allantoin arises from uric acid by the action of uricase. By action of allantoinase, allantoic acid is produced, forming nearly 0.5% of wet weight of faeces of Lepidoptera. Allantoic acid constitutes 25% of the waste product of pupal metabolism forming the meconium.

Detoxication

Metabolic events have been studied in toxicology of insecticides. Several insects have been known to possess the detoxication mechanisms.

The detoxication mechanism renders the organic toxic substance into harmless products which gets excrected. In insects this has been brought about by several methods. In Orthoptera, Hemiptera, Coleoptera and Lepidoptera, the phenols are conjugated to glucose to form β-glucosides. 2-4 Dinitro-o-cresol and phenothiazine are tackled this way. In the housefly naphthol is converted into etheral sulphate. Cockroaches acetylate amino groups; houseflies metabolise hexa chloro cyclohexane (HCH) by conjugating it with glutathione or cysteine. Oxidations occur as a detoxicating mechanism in cyclodiene poisoning. Rarely reduction of organic compounds is met with. These examples illustrate that poisonous substances get converted or linked up with substances, making them harmless to the insect. Several detoxication mechanisms are indeed poorly understood, though some of the major pathways involved have been elucidated in toxicological studies.

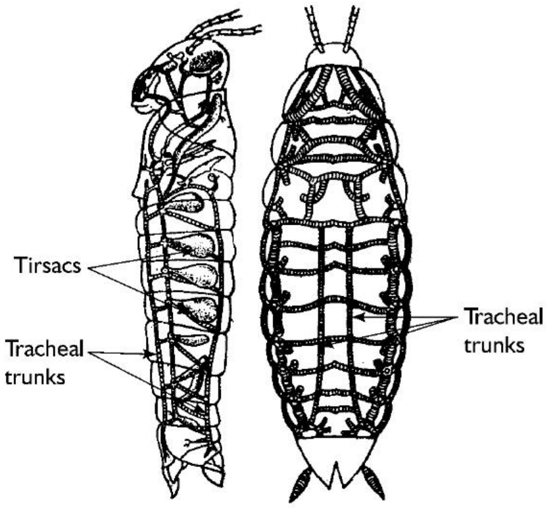
◆ Chapter 10

Tracheal System

The processes involving exchange of gases–oxygen into the insect and carbon dioxide out into the environment–and respiratory metabolism whereby this oxygen is combined with the substrates to produce energy, comprise respiration. The mechanics of respiration dealing with the various methods of intake of oxygen and the structure of the insect respiratory system in general, are discussed below. Since the production of energy, the key note of respiratory metabolism, involves complex reactions (involving the conversion of food substances and the breaking down and synthesis of various compounds) taking place at a cellular level, this aspect is not dealt with here.

The respiratory system of insects comprises a network of thin-walled, reinforced tube called the tracheal system which carries oxygen directly to the various tissues. Intake of oxygen is through paired, segmentally arranged lateral openings, the spiracles. The tracheae divide and subdivide, their ultimate branches, the tracheoles (0.1-0.2 µ. in diameter) ending in the tissue. The tracheae are generally circular in cross-section and have a thin, but complex, chitinous, spiral winding or taenidia, to strengthen their walls and prevent their collapse and this also serves to keep the tracheae always open. This cuticular lining is more dense near the spiracles and is absent in the finer tracheolar branches. The finer branches of the tracheoles ultimately terminate in a tracheal end cell, breaking therein into still finer tracheal capillaries less than 1µ in diameter. The mode of termination in the tissues may be intracellular or intercellular. The tracheae are ectodermal in origin, arising from ingrowths or invaginations of cells. With the further development or growth of these invaginations, they divide or ramify till they reach all the tissues of the segment. It is within the terminal tracheal end cells or tracheoblasts, that the tracheoles develop as fine, intracellular canals. With the appearance of the lumen, first in the outer tracheal trunks and then in others, the cuticular intima is developed and is thrown into spiral folds. As such, the walls of the tracheal system become continuous with the integument and like the integument, also contain chitin and protein. Even though it is generally believed that the tracheoles lack the spiral thickening, studies have shown that these thickenings are present.

The spiracles lead into a short, spiracular trachea, subsequently dividing into (a) dorsal tracheal branch supplying the dorsal muscles and dorsal vessels, (b) the visceral tracheae supplying the digestive tract, fat bodies and gonads, and (c) the ventral tracheae supplying the ventral musculature, the nerve cord, legs, etc. The main longitudinal trunk is formed as a result of the fusion of the anterior and posterior branches of the spiracular, dorsal, ventral and visceral branches of each side (Fig.10.1). Tracheal commissures or transverse connections may be found in almost all the segments, and ventral commissures connecting the tracheal system of each side. Each of these tracheal branches, longitudinal and transverse, may give rise separately to smaller branches. Two main types of tracheal trunks may be recognised:



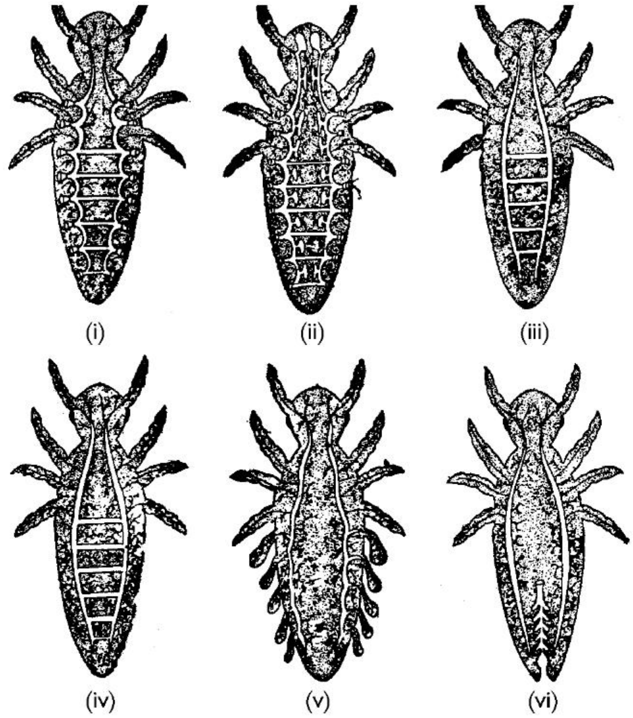
▲ **Fig. 10.1** *The tracheal trunks and air sacs of the grasshopper (left) and the trunks of the cockroach (right)*

1. The lateral longitudinal trunk alone.
2. The dorsal, ventral and longitudinal trunks with dorsal and ventral commissural tracheae.

In some insects, notably the grasshoppers, saccular dilations or expansions may be found in the course of the tracheae and are called air sacs and these lack the chitinous lining. They are, therefore, easily inflatable or distensible. Their arrangement may vary from small to large sacs and serves only to increase the volume of air. The more the sacs, the greater the air volume and this will be of advantage in flight, because it lowers specific gravity. In aquatic insects such sacs enable them to float at any level in water and facilitate increased ventilation to the tracheal system.

Types of Tracheal System

Based on the location and functioning of the spiracles, the tracheal systems (Fig.10.2) are classified into four major types:



▲ **Fig. 10.2** *Organisation of tracheal system in insects (diagrammatic). Top from left to right (i) simple type, (ii) type with air sacs, (iii) metapneustic. Bottom from left to right: (iv) closed type without spiracles, (v) similar but with gills bearing tracheae, (vi) rectal gills (adapted from V.B. Wigglesworth, The Principles of Insect Physiology, English Language Book Society and Methuen & Co. Ltd, U.K, 1965).*

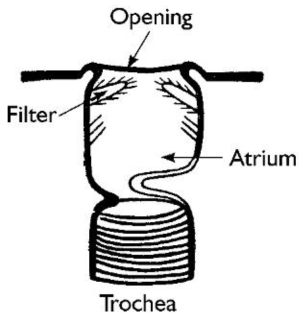
1. Holopneustic or polypneustic with eight or more functional spiracles.
2. Hemipneustic with one or more spiracles becoming non-functional.
3. Apneustic with none of the spiracles being functional, air entering the tracheal systems by diffusion through the general body surface or gills.

4. Hypopneustic without the full complement of ten spiracles, but where one or more pairs disappear completely, as in thrips, with two pairs of thoracic and two pairs of abdominal spiracles, or only two pairs as in scale insects.

The hemipneustic type presents a variety of modifications like (a) Peripneustic, with six thoracic and abdominal spiracles open and metathoracic spiracles closed (larvae of Neuroptera, Mecoptera and Lepidoptera); (b) Amphipneustic, only prothoracic and posterior abdominal spiracles open (larval Diptera); (c) Propneustic, only the prothoracic spiracles open (pupae of some Diptera); and (d) Metapneustic, only the last pair of abdominal spiracles open (larval culicids and aquatic larvae of some beetles).

Spiracular Structure

In general a spiracle is surrounded by an annular sclerite, the peritreme and leads into a chamber or atrium. In many insects there is a mechanism consisting of one or more muscles, connected with cuticular outgrowths and called the closing apparatus (Fig. 10.3). This serves in the proper functioning of the spiracles and prevents excessive loss of water vapour. It may also be mentioned that it is through the spiracles that gaseous exchange takes place. Also during ecdysis, they are the openings through which the old tracheal lining is pulled out. The atrium is also provided with hairs or other outgrowths to prevent water loss. There are several types of spiracles both in the early instars and adults. In the thoracic spiracles of grasshoppers each spiracle is a slit like aperture with two movable valves or lips. Special muscles arising from a process close the aperture. The abdominal spiracles of grasshoppers lack the valves or lips and the integument is inturned or inflected to form the walls of the atrium. In many others the lips or valves carry processes of different kinds and primitive insects are devoid of both lips and closing apparatus.



▲ **Fig. 10.3** *Spiracular structure (redrawn from Snodgrass, 1935)*

The entry of air into the tracheal system is controlled by the opening and closing of the spiracles. As such, control of the respiratory activity results from diffusion control due to the opening and closing of the spiracles regulated by the nervous system. During respiration, there is the inspiratory phase letting in air through spiracles and larger tracheae, a compressatory phase increasing air flow resulting from a dorsoventral flattening of the abdomen, and an expiratory phase. During inspiration, the main trunks and air sacs become filled with air. There is an increase in pressure during the compression of the abdomen and this helps in the expansion of the smaller tubes. Compression and decompression drive the air deeper and deeper into the tracheoles carrying the air directly to the cells of the tissues. The amount of fluid at the distal end of the tracheoles is affected by the osmotic concentration of the surrounding fluid and the removal of the fluid takes place during metabolic activity with a low oxygen supply. The amount of carbon dioxide produced in metabolism is generally lesser than the oxygen consumed and as its rate of diffusion through air is also slower, carbon dioxide passes through the same route, i.e. comes out through the spiracles. A certain amount is also eliminated through the body surface. A stationary insect generally uses 0.6 to 3 litres of oxygen/kg/hr. But during flight this increases considerably from about 12 to 180 litres. A thoracic pumping device helps in this by hyperventilation.

Respiration in Aquatic Insects

Respiratory mechanisms undergo the following diverse modifications in the aquatic insects.

1. Development of Hydrofuge Hairs

Very common in culicid larvae where the spiracular area develops special hairs having a coating of non-wettable wax on one side enabling the larvae to stay in the water surface and expose their spiracles to the air. In many, like *Culex* larvae, spiracles are placed at the end of the long siphon.

2. Tracheal Gills

The immature stages of many aquatic insects possess a tracheal system containing air but lack a distinct communication with the exterior, the spiracles being closed or absent. In such insects there is an extensive network of fine tracheal beneath the integument, either concentrated in some regions or distributed all over as in the tracheal gills of immature stages of Ephemeroptera, Trichoptera, and Plecoptera. In some caddis-fly larvae there are more than 60 tracheal gills and these as well as the lateral gill plates of the ephemerid nymphs come into play or take an active part in respiratory activity particularly in the summer months and when water is poor in oxygen.

3. Air Stores

Many aquatic insects like *Notonecta* carry on the ventral surface a fine set of erect hydrofuge hairs which hold between them a thin layer of air in the form of renewable bubbles. Dytiscidae carry lot of air beneath their elytra as bubbles attached to the posterior extremity. These bubbles are usually in communication with the spiracles and tracheal system. An aspect of particular reference in *Notonecta* and *Corixa* is that these air stores on the ventral surface of the abdomen are used for respiration and those between the head and the thorax for a hydrostatic function. The air stores thus act as physical gills because as the oxygen in them is removed and used up, the insects are forced to come to the surface to renew the bubble.

Many other aquatic insects like the hydrophylid beetles carry air as a thin layer held by a clothing of fine hairs spread over the body and not as bubbles, and when submerged in water these give a silvery appearance. With the hydrofuge hairs sufficiently closely set and almost free from complete wetting, a steady flow of oxygen sufficient for respiration could be maintained independently without the frequent visits of insects to the surface. This naturally requires enough surface area in relation to the oxygen requirements of the insects. Air stores of this type have been termed the plastron, forming a thin layer of gas of nearly constant volume, and respiration by this means is known as plastron respiration. The plastron hair-pile in such insects is a system of minute hairs and in an aquatic bug *Aphelocheirus,* investigated in great detail by Thorpe[*], 2,500,000 hairs per sq. millimetre surface are found. Many aquatic insects make use of the bubbles of gas given off by plants rich in some aquatic environments. They take them up through the hydrofuge surfaces and some take oxygen from the intercellular spaces of water plants.

4. Blood Gills

Thin blood-filled sacs without tracheae project from the exceedingly thin body surfaces in some dipterous larvae (*Chironomus*) or as evaginations from the rectum as in *Simulium.* The anal papillae in mosquito larva have often been suggested to have a respiratory function and experiments now reveal that they are really active sites of oxygen uptake. The anal papillae in some *Aedes* larvae are elongated and highly tracheated and appear to serve a respiratory function.

5. Cutaneous Respiration

This is important to many aquatic larvae even when tracheal gills are present and particularly in the larvae of *Chironomus* and *Simulium*, where the integument is extremely thin. Respiration is accompanied by simple diffusion of gases through their skin.

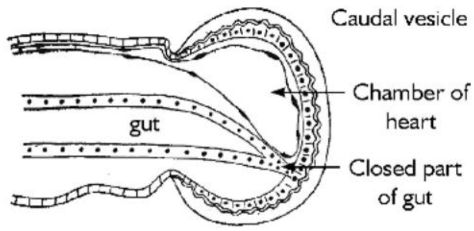
[*] Thrope, W.H. 1950. Biol. Rev., 25: 344–90.

6. Spiracular Gills

In some aquatic insects filamentous outgrowths of the ectoderm without any connection to the body cavity are developed. The cuticular wall in such cases becomes excavated to form air spaces which become connected to the tracheal system. Any air-filled space which is in contact with spiracles makes available its oxygen to the tracheal system thus functioning as a temporary air store. They occur in insect larvae of several Diptera and Coleoptera and come into play when the water dries up.

Respiration in Parasitoids

In many hymenopterous parasitoids and dipterous parasitoids the tracheae of the first instar larva are filled with fluid and are nonfunctional. Exchange of gases takes place only between the tissue fluid of the parasitoid and the host. The tracheae become filled with air only in the second instar and there is a fine and extensive tracheal supply to the skin. Many such parasitoids in the earlier stages have caudal processes or filaments or vesicles which have been ascribed the respiratory function. Sometimes the front of the egg shell may be modified into a kind of aeroscopic plate. The caudal vesicles of some of the Hymenoptera are evaginations of the wall of the hindgut, filled with blood and appear to be a centre of active oxygen uptake (Fig. 10.4). So also are the tails of agromyzid larvae which play an important part in oxygen absorption. In many parasitic Hymenoptera the pedicel of the egg is long and protrudes externally through the body wall of the host and functions as a sort of respiratory tube. On hatching, the larva inserts its posterior spiracles into this tube to breathe the atmospheric air.



▲ **Fig. 10.4** *Larva of Apanteles with the caudal vesicle (redrawn from R.F. Chapman, 1969)*

Most insects do not possess any respiratory pigment. However, the larva of *Chironomus*, the aquatic bug *Anisops*, and the larva of *Gasterophilus* which is endoparasitic have haemoglobin in solution in the blood.

◆ Chapter 11

Circulation and Blood

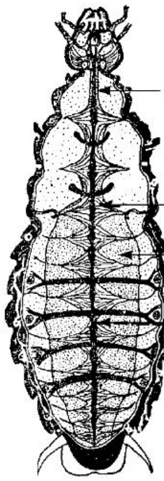
INTRODUCTION

The circulatory system shows a close link with the body cavity. In insects it is formed by the fusion of the lumen of the coelomic sacs with the perineural sinus of the haemocoele. The body cavity is not bound by an epithelial covering and contains the blood. The visceral organs lie freely bathed in this blood, and the insect body cavity is a large blood sinus. This cavity is the haemocoele.

The circulatory system is of the open type. For most of its course the blood simply flows through the sinus of the body cavity irrigating the various tissues and organs. A pumping heart is only of significance in directing part of the blood flow.

Components of Circulatory System

The chief organised structure for driving blood is the dorsal vessel, lying below the dorsal body wall and extending from the hind end of abdomen into the head (Fig. 11.1). This tube is differentiated into a posterior pulsatile heart situated generally in the abdominal region, and an anterior conducting part projecting into the head called the aorta. The heart is a chambered tube and is lodged in a sinus dorsally known as the dorsal or the pericardial sinus. This sinus is a dorsal region of the haemocoele cut off by a fibro-muscular septum called the dorsal diaphragm. The heart is suspended by elastic fibres or strands from the terga, and often such strands hold it on to the dorsal diaphragm also. The heart is often with segmental swellings forming the chambers. Typically each chamber possesses a pair of vertical or oblique slits laterally, called ostia, one on each side. In *Periplaneta*, the heart shows 13 chambers, in *Japyx* 10, in *Lucanus* 7, and in *Musca* 3; chambers are merely indicated by paired ostia in Siphunculata, Mallophaga and *Nezara*. The ostia are lateral and the wall of the heart is reflected inwards at each ostium to form an auricular valve preventing backflow of blood into the dorsal sinus.



▲ **Fig. 11.1** *Diagram of vessels and sinuses of the cockroach (after A. Kaestner)*

Histologically, the heart is composed of a single layer of cardiac cells carrying large nuclei. The cytoplasm contains within it striated muscle fibrillae which are absent in the periphery, and the cells have outer and inner sheaths probably derived from sarcolemma. Arising from the terga and situated fanwise over the dorsal diaphragm are the alary muscles so called because of their wing-like shape. In certain insects like Collembola, Anoplura and dipterous larvae the muscles are directly attached to the wall of the heart. These muscles show a paired arrangement roughly corresponding to the number of cardiac chambers. *Periplaneta* shows 12 pairs, the honeybee 4, and *Chironomus* 2.In most insects the posterior end of the heart is closed. But in some insects like *Aleyrodes* and *Culex* a pair of posterior ostia are present.

The aorta is the slender anterior continuation of the heart into the head, terminating near the brain, and commencing usually from the first abdominal segment. It forms the principal and the only artery. Its junction with the heart is provided with the aortic valves. In some insects the anterior end terminates like a funnel, in others, it bifurcates to form the cephalic arteries, which may or may not further divide. In some insects the aorta gives off diverticula in the thorax as in odonate nymphs and *Dytiscus*, called the aortic ampullae. In general the aorta is non-pulsatile, but is pulsatile in *Dytiscus*, and in certain Lepidoptera the diverticula perform rhythmic contractions independent of the heart. Histologically the aorta is similar to the heart. The haemocoele or the general body cavity filled with the blood represents the larger part of the circulatory system. It surrounds all internal organs. The dorsal sinus is really a part of this cut off by the dorsal diaphragm. The dorsal diaphragm extends from the hind end of the abdomen to the anterior limit of the heart. Stretching across the abdominal cavity above the nerve cord is a fibromuscular septum called the ventral diaphragm, having the ventral or the perineural sinus underneath it.

This is well developed in Acridoidea and Hymenoptera. The subdivisions of haemocoele are directly in communication with the major central part called the visceral sinus. In the thoracic segments the ventral diaphragm may extend into legs to form septa of a membranous kind.

Besides the principal pulsatile heart, there are other accessory pulsatile organs in many insects. These are special accessory hearts in connection with blood supply to particular organs. In *Apis, Locusta, Periplaneta* and some other examples, situated in the head below the antennae are the antennal hearts, in *Notonecta* are pulsatile subpedal sacs, in *Nepa* are thoracic hearts, and hearts in the wing itself in Odonata, *Dytiscus*, Sphingidae, *Apis* and *Musca*.

Dynamics of Circulation

The circulation is chiefly effected by the pulsation of the heart. The heart rhythmically contracts in the antereo-posterior direction. The cardiac cells possess an automatic capacity to contract and relax irrespective of nervous excitation. This is clearly illustrated in insects like *Belostoma, Aeschna* and others where the heart is not supplied with nerve cells or ganglia. The contraction is simply myogenic. The cardiac cells possess this property which brings about the automatic activity of contraction. The contraction begins in the last segment and proceeds forward. Though the contraction is initiated by myogenic means, its rate and rhythm are controlled by nervous means. But the activity and the control of the accessory hearts are not known.

When the heart expands, during diastole, a negative pressure forces the blood from the pericardial sinus to enter the heart through the ostia. During systole, a positive pressure is set up and the ostia get closed and the blood is driven forward to the chamber in front. The blood is forced forward by the heart from behind into the aorta and thus into the head. Here the blood circulates and then percolates into the visceral sinus where it flows due to the gentle movement of the diaphragm. An undulatory movement of the ventral diaphragm forces blood back along the perineural sinus. The thoracic pulsatile hearts are of great use in bringing about circulation of blood in the thorax, a region with extra musculature and the locomotor organs. The diaphragms and septa continuously move up and down, thus maintaining circulation. The blood is finally drawn up into the dorsal sinus by the contractions of the alary muscles. From there it again enters the heart and the circulation continues.

The rate of the heart beat is variable in insects. In *Periplaneta* it is 49/min, in *Oryctes* 18/min, and in *Hippobosca* 120/min. There is a pattern for the fall in pulse rate: pulse rate which is 82/min in the first instar, falls to 63/min in the third instar, to 45/min in the fourth and to 39/min in the adult. The rate increases as an insect becomes active. Increase of temperature also increases pulse rate. In diapause the pulse rate falls to the minimum.

In a number of insects like *Bombyx* larvae, Diptera, Coleoptera, Hymenoptera and their larvae, the heart can show a reversal of heart beat. This probably occurs due to mechanical reasons like clogging, or injury which sets up a disturbance of the normal automatism. The change has no deleterious effect on the insect, the blood is forced through the hind end and the circulation is completed. The heart thus shows a remarkable type of tubular structure where the chambered and valved condition have little significance. The simple circulation of the insect is, however, an efficient one.

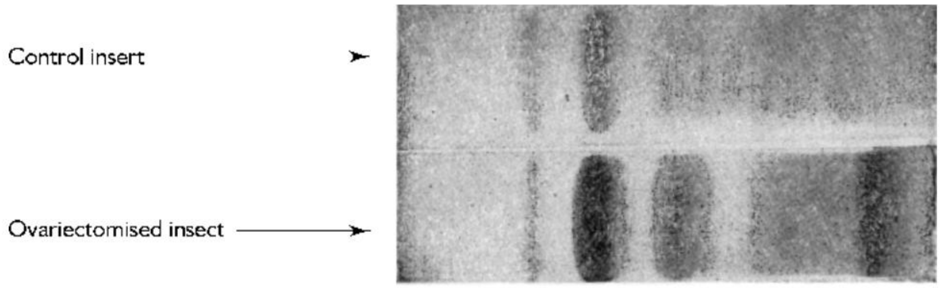
Blood Composition

The blood or haemolymph consists of a number of nucleated blood cells or haemocytes suspended in a fluid plasma. The quantity of the plasma and the number of haemocytes vary with insects, and even in the same insect under different conditions.

The plasma is nearly 90 per cent water though the water content may vary. The blood volume increases prior to a moult and decreases just after moult; increase in volume is by discharging water into blood from tissues and decrease is by return of water to the tissues. Mild variation in blood volume occurs in other stages, as in grasshoppers where there is a decrease in blood volume during day and an increase the late evening after feeding.

Of the inorganic anions in blood, chlorides are the most abundant, especially so in apterygotes and hemimetabolous examples. Carbonates and phosphates also do occur in fairly large quantities, phosphates more so in *Carausius*. Except in Lepidoptera and Hymenoptera, the most abundant cation is sodium. Potassium is lower, and sodium/potassium ratio which though is variable, has been explained to have phylogenetic significance. It is also suggested that activity is to some extent inhibited by greater potassium concentration as in the periods of moulting or after feeding. The concentration of magnesium is high in the plasma, traceable to the high magnesium content of chlorophyll eaten. In Phasmida it completely replaces sodium. Calcium is less important but is valuable in the development of the end plate potential at the muscle. *Bombyx* larva shows 15:46:24:101 as the ratio for Na:K:Ca:Mg, while in the adult the ratio is 14:36:14:47. There is generally a fall in the magnesium content in the adult Lepidoptera. Metallic trace elements of copper (a constituent of tyrosine), iron (present in cytochromes), zinc and manganese have also been found in insect blood.

Organic constituents of the blood of insects, comprise a high level of amino acids, trehalose and glycerol or its equivalent. Trehalose is the source of energy; activity reduces its concentration in blood while it rises after feeding. Glucose and fructose occur in the plasma of *Apis*. About 35-65 per cent of non-protein nitrogen of blood is due to amino acids and most insects have a high concentration of glutamine, proline, arginine, lysin and histidine. Variations of amino acids related to specialised activities are noticed. An increase in tyrosine before moulting, which also aids in tanning of skin has been observed. Rise in glutamic acid and aspartic acid in the larval *Bombyx* help in silk production. A number of proteins are available in blood, as much as 21 in *Locusta*, especially noticeable in electrophoresis, but many occur at different times of the life history (Fig. 11.2). Sex proteins belong to this type which appear at reproductive periods in insects like cockroaches. Some enzymic proteins are also seen in blood at various times like tyrosinase, trehalase. etc. End products of nitrogen metabolism also will be seen in blood like uric acid, and sometimes allantoin, urea and ammonia.



▲ **Fig. 11.2** *Electrophoretogram of haemolymph of Dysdercus showing patterns of proteins in ovariectomised (bottom) and control (top) insect. The ovariectomised insect shows retention of proteins which get used in the control in egg formation.*

Three arrangements in plasma constitution have been suggested, viz.

1. A basic type, seen in ephemerids, odonates, Orthoptera and Homoptera where sodium and chloride decide the osmolar concentration.
2. Where the chloride content is low, relative to sodium and amino acids present in high concentration, as is met with in Trichoptera, Mecoptera, Diptera, and many Coleoptera.
3. Amino acids accounting for over 40 per cent of total osmolar concentration seen, as in Lepidoptera and Hymenoptera.

Pigments occur in plasma, like haemoglobin in *Chironomus*, where it is helpful in respiration. No other respiratory pigment occurs in the blood of insects, but the blood may be coloured due to other pigments like green insectoverdin in Lepidoptera and locusts, blue mesobiliverdin in starving locusts, purplish red protoaphin in aphids, and carotene, xanthophyll and flavins in *Bombyx* larva.

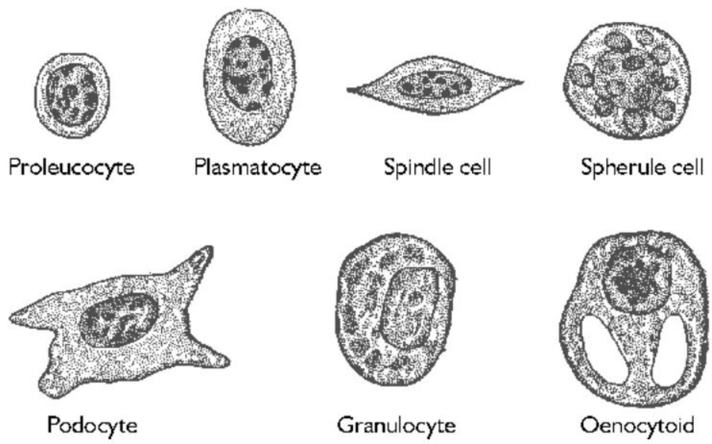
Many insects show an osmotic pressure of 7–8 atmospheres, which is of considerable, importance in controlling the water content of cells. The blood is slightly acidic with pH 6–7 but may sometimes be alkaline as in *Chironomus* where the pH is 7.2–7.7. Under normal conditions, phosphates and bicarbonates form important buffers.

From the functional point of view blood plasma is the major medium for transport of various materials within the body.

Nutritive substances are carried by the blood from the gut to the storage sites where they are metabolised. Excretory materials are taken to the malpighian tubes, and the hormones are transferred to the sites of the target organs by plasma. Carbon dioxide dissolves readily and oxygen dissolves to a lesser extent in it. Blood also helps in storage like trehalose from fat body, amino acids and tyrosine. Water storage is important and the liquid plasma may help as a hydrostatic skeleton as in extending appendages and ptilinum. Reflex bleeding is forcible ejection of blood through pores by increasing hydrostatic pressure, forming a defensive mechanism. In such cases the blood is drawn back into the body after sometime.

Haemocytes

Haemocytes are blood cells suspended in the plasma (Fig. 11.3). There are different types of cells, three of which may be considered as major. Prohaemocytes are rounded cells



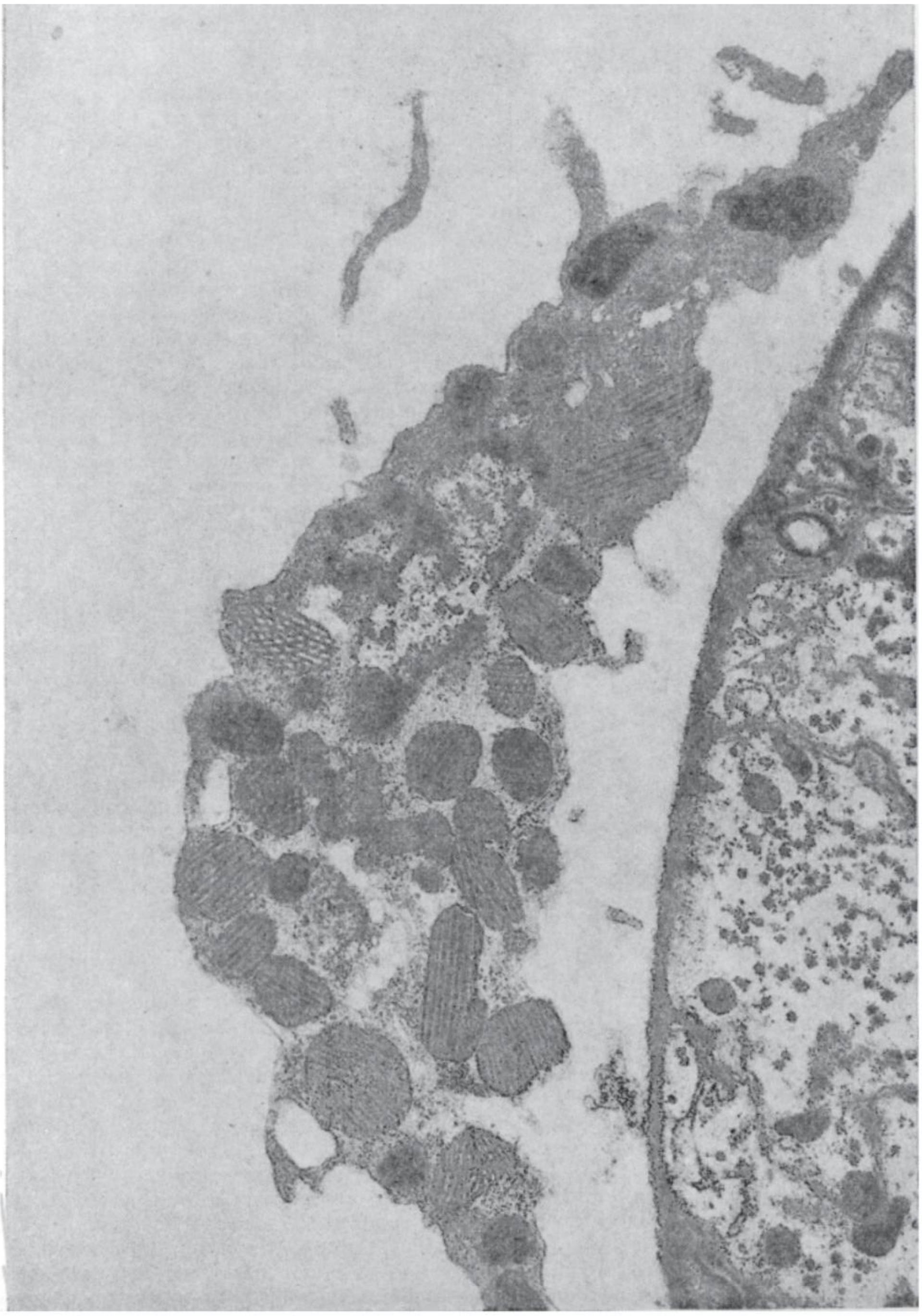
▲ **Fig. 11.3** *Haemocytes (R.L. Patton, Introductory Insect Physiology, Saunders Co.)*

bearing large nuclei and cytoplasm strongly basophilic. These divide and give rise to others. Plasmatocytes are the most abundant, with variable form, basophilic cytoplasm and phagocytic function (Fig. 11.4). Granulocytes show cytoplasmic acidophilic granules. Cystocytes or coagulocytes are with small nuclei and hyaline cytoplasm with granules and probably are modified granulocytes. Oenocytoids, spherule cells, and adipohaemocytes are special blood cells, and not seen in all insects. Oenocytoids are large basophilic cells with canals, crystals and rows of granules, seen in Lepidoptera, Heteroptera and Coleoptera. Lepidoptera and Diptera have spherule cells, which are spheroidal cells with inclusions which are large, acidophilic and nonrefringent. Adipohaemocytes, also called spheroidocytes, are seen in Lepidoptera and Diptera, and contain cytoplasmic refringent fat droplets and other inclusions. It is maintained that prohaemocytes give rise to the different varieties of cells. Some insects possess special blood-cell forming (haemopoietic) organs as in caterpillars where they are capsulated and thoracic in position; and in *Musca* larva they are non-capsulated. Haemopoeitic organs do not exist in adult insects.

The haemocyte number fluctuates in an insect; free cells circulate in millions in *Periplaneta* while in *Chironomus* no free cells will be observable. The number varies according to the stage of the insect, in *Sarcophaga* it will be 8000/mm^3 in larva, 3400/mm^3 at pupation, and 12,000/mm^3 in the pupa. Generally the number in insects will be 20,000–40,000/mm^3. Types of cells made out by differential counts also vary.

Functions of Blood Cells

Phagocytosis is the most common function of blood cells–ingesting foreign matter, bacteria etc. At metamorphosis there is an increase in the number of phagocyte cells to clear tissue debris. In crickets, well developed phagocytic organs are present near the heart muscles, helping in the removal of particles from blood. Larger bodies which could not be easily phagocytosed are encapsulated by concerted action of blood cells. The haemocytes aggregate and arrange in layers to form the capsule. Parasitoids thus encapsulated die of asphyxiation. Hymenopteran parasitoids which enter insect blood of the host prevent capsule formation by the host by continuous movement. Haemocytes help in activating the thoracic gland and corpora cardiaca in *Mimas* and *Rhodnius*. Haemocytes also help in formation of fat bodies. They are also involved in intermediate metabolism as in the spherule cells of *Sarcophaga*. By their breakdown blood cells provide nutriment for tissues as in *Ephestia*. Wound healing and coagulation form another functional role of blood cells. Tissues that are damaged will be phagocytosed and a cellular network formed, and the plasma coagulates to form a wound plug. It is claimed that blood cells bring about clotting. The cystocytes of *Gryllotalpa* stop movement and their cytoplasm spreads and vacuolates. From



▲ **Fig. 11.4** *Phagocytic haemocyte of the salivary gland of the cockroach at the site of a wound. The cytoplasm contains several ingested particles. x13,600* this focal point plasma starts clotting. In caterpillars cystocytes extend pseudopodia and within the pseudopodial network the plasma coagulates. In Coleoptera both these types of clotting are met with.

Haemocytes play a part in forming connective tissue which supports and binds tissues together. The connective tissue is noncellular and membranous. While various connective tissues are associated with the support of specialised structures and are formed as secretions from the epithelium concerned, there are examples where plasmatocytes contribute to the formation of the structure. In the basement membrane of epidermis the plasmatocytes help in laying down the mucopolysaccharide component. Based on circumstantial evidence, detoxication has been claimed to be effected by haemocytes. Inactivation of insecticides has been ascribed to the enzymes of blood cells.

◆ Chapter 12

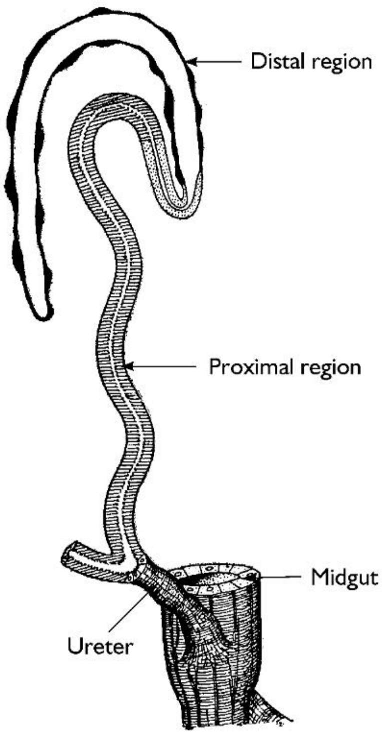
Excretion

The maintenance of a constant or stable internal environment in insects is essential and the excretory system plays an important role in this process, by eliminating nitrogenous waste products, resulting from the breakdown of proteins. The haemolymph being the internal medium, the excretory system also functions by controlling the ionic composition of the blood. Several structures are associated in discharging the function of excretion, the principal structures being the malpighian tubules. Besides them the fat bodies play the role of an accessory excretory structure. In addition the nephrocytes, which are scattered or aggregated cells and the cephalic glands or labial glands in some apterygotes also help in excretion. In some insects, parts of the digestive tract often assume the excretory function.

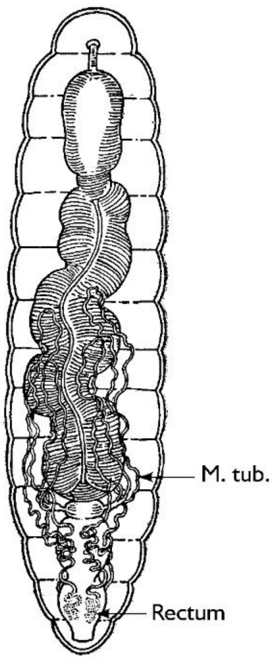
Malpighian Tubules

These (Fig. 12.1) are long and slender, blind, often convoluted tubes of varied length and number, occurring in all the insects. Malpighian tubules lie in the haemocoele and open into the gut at the junction of the midgut and hindgut. They were first discovered by Marcello Malpighi in 1669 but were so named only in 1829 by Meckel. They range from four in number in Hemiptera and Thysanura to about 200 in Orthoptera and Odonata. They are absent in Collembola and aphids and poorly developed in the apterygotes. The primitive number is, however, considered to be six, always arranged in multiples of two but mosquitoes have strangely five. Papillae, probably representing aborted malpighian tubes have been found in Protura and Strepsiptera.

The arrangement of the malpighian tubules is varied and they normally lie free in the body cavity. Sometimes they may be closely connected with the wall of the rectum by their terminal ends as is the case in most of the lepidopterous larvae (Fig. 12.2) and in some beetles. Based on the relationship of the malpighian tubules with the digestive tract, there are several types of malpighian tubules or systems. The primitive or the fundamental type have long and convoluted tubes, lying almost free in the body cavity as in Orthoptera. They may be blind or attached to and lying within the tissues surrounding the hindgut. In the coleopterous type, the tubes are clearly attached distally (cryptonephridial arrangement) to one side of the gut or may be disposed of around the rectum in a simple convoluted layer. In the hemipteran type, the tubes are free at their distal ends but the proximal half is opaque and the distal half is clear. Lastly, in the lepidopterous type, cryptonephridia are also present, but like the hemipteran type, they also show differentiation into a proximal region filled with solid particles and so opaque, and a distal clear region, filled with a



▲ **Fig. 12.1** *Malpighian tubule of larval Drosophila showing differentiation into two regions (after A. Wessing)*



▲ **Fig. 12.2** *Caterpillar of Malacosoma showing malpighian tubules investing the rectum (Snodgrass, 1935)* clear fluid. When the arrangements of individual insects are studied many other modifications can be seen. The malpighian tubules are covered with peritoneum and have a rich supply of tracheoles and it is the tracheal branches that bind these to the intestine and adjacent organs.

Structurally the wall of the malpighian tubule is made up of 4-6 layers of epithelial cells. Each cell has three distinct regions. A basal one which is filled with vacuoles, mitochondria, and other intracellular components. A middle region with the nucleus, and an apical region with a brush border. The brush border may be of two kinds, the honeycomb border containing a number of closely packed, parallel filaments or microvilli and the typical brush border with separate independent filaments. There is distinct physiological differentiation between the proximal and the distal regions of the malpighian tubules. The proximal part is mostly concerned with the reclamation of water and useful materials. In the distal region, there is one-way penetration of the walls of the tubules, the filtrates penetrating either by diffusion or by active secretion. It has also been shown that the contents of each tubule is fairly alkaline in the upper part and fairly acidic in the lower part. In aquatic larvae, during the regulation of water by osmoregulation, the anal papillae are permeable to water which is subsequently excreted by the malpighian tubules. Re-absorption of essential substances, particularly sodium and potassium, takes place either in the proximal parts of the tubules or in the region of the rectum.

In insects without malpighian tubules, as in Collembola, uric acid granules collect in the urate cells present in the fat body. As the insects become older, these urate cells become increasingly loaded with the granules. In the cockroach, the malpighian tubules do not contain uric acid, but accumulates throughout life in the urate cells, which appear in the developing fat body in the embryo and increase in size throughout life. This process of excretion of the deposition of excess products of metabolism, is called storage excretion.

Collembola and Thysanura also possess special tubular glands opening above the base of the labium by a duct often called the labial kidneys. The digestive tract may also play a role in the regulation of the excretory process, particularly the regulation of water. The periodical casting off of the midgut epithelium of Collembola appears to be a part of the excretory process.

Excretion in insects is chiefly in the form of uric acid. As a result of metabolism, uric acid in the form of sodium or potassium salt is released into the body. The malpighian tubular epithelium can selectively remove this into its lumen. This is described as a secretory absorptive process, and the secretion forms urine. Urine is poured into the gut and passes out as a droplet. As in the case of the beetle, there is always re-absorption of water at the rectum by the papillae where the malpighian tubular ends are invested on rectal walls. This secretory process is accompanied by water absorption at the rectal level. In forms like *Rhodnius*, the tubule itself can perform a process of dehydration. In larvae of cerambycid beetles and Diptera, the malpighian tubules show presence of calcium carbonate as granules which often collect together as calcospherites. The tissues of the malpighian tubules have also been known to contain insectorubin and some vitamins. In *Schistocerca* are the tissues of the malpighian tubules rich in riboflavin and other water soluble vitamins like niacin, pantothenic acid and ascorbic acid. Several enzymes have also been reported to be present in the malpighian tubules, such as alkaline and acid phosphatases, lipase and succinic dehydrogenase. Additional functions have also been attributed to malpighian tubules. Silk production in *Planipennia*, viscous secretion which is whipped into a foam as spittle in cercopids, production of dipeptidase in the beetle *Necrophorus*, etc., are some of the non-excretory functions, attributed to malpighian tubules.

Nephrocytes have been described to store excretory matter in the larva of *Apis*.

◆ Chapter 13

Water and Salt Regulation

Water constitutes 50 to 90 per cent of the body weight of the insect. Reduction of water content up to about 10 to 15 per cent will have lethal effects. The tissues mostly contain water. The level of inorganic salts also has significance. Water and salts together produce osmotic effects which in turn influence the water distribution.

Most insects are land-living and they tend to lose water from the body and the respiratory surfaces by evaporation. Loss of water through cuticle is minimised by the presence of the wax layer of the epicuticle which is one molecule thick and is called the monolayer. The orientation of this layer may be over two monolayers through the wax in insects that are highly waterproof. However, the respiratory surfaces are a potential source of water loss. This has been overcome to some extent by invaginated regions of these surfaces. Additionally closure of spiracular opening for the minimum period that would be possible also helps in preventing evaporation.

A second major source of water loss is along with urine and faeces. The water content of faeces is of importance in insects like grasshoppers; in *Schistocerca* during dry season the fresh fecal pellets are dry but are more wet during the rainy season with fresh vegetation. Considerable amounts of water pass along with urine, especially in liquid feeders. But all the water flowing along malpighian tubes is not lost, because in insects living in dry areas there is absorption of water through the rectum (nearly 40 per cent). In *Schistocerca* it has been found that re-absorption of water from the rectum is regulated according to the water requirements.

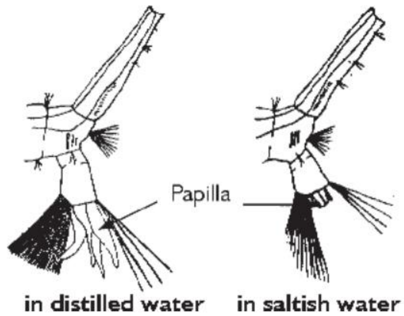
In insects with cryptonephridial arrangement, fluids around the rectum has an osmotic pressure assisting in drawing water from the rectum. This osmotic pressure could be altered depending on the environment.

The ileum has been found to be associated with disposal of water in *Dasira* (Pentatomidae) when it is expanded together with the proximal part of the malpighian tubule. The gastric caecae and the ileum steadily pump water out of the haemolymph into the hindgut or specialized regions close to the ileum.

Insects gain water from food and some insects do drink water as in *Lucilia*. In *Periplaneta* water could be absorbed through the cuticle, and in Collembola through the ventral tube. Under desiccated conditions, *Tenebrio* larva can absorb water from humid atmosphere. Larvae of *Ephestia* normally obtain considerable water from the oxidation of food.

Haemolymph contains salts and the concentration of salts is maintained at a steady level despite entry of salts through food. For example carrot leaves contain Na: K: Ca: Mg :: 25.6 : 176.9 : 214.5 : 35.6 equiv/kg. wet weight. *Papilio* larva feeding on carrot leaves has a proportion Na : K: Ca : Mg : : 13.6: 45.3 : 35.4: 59.8; this condition is maintained in the animal rigorously.

In fresh water insects, the haemolymph is hypertonic to water and there is a tendency for water to pass into the insect. The cuticle prevents entry of water by reversed monolayer in *Dytiscus*. In many water beetles and aquatic bugs the skin is relatively impermeable. However, in a very large number of aquatic larvae the cuticle is permeable because the lipid layer is absent. In the larva of *Aedes,* anal papillae are permeable and water up to one-third of the body weight could be absorbed through them. This water is eliminated by copious production of urine. Due to the production of urine in large quantities, salts also get removed; these salts will be actively reabsorbed at the rectum. It is also known that salts are absorbed by the anal papillae in forms like *Aedes*, from very dilute solutions and thus salts from water bodies could find their way in. Depending on dilution, the papillae of larvae (*Culex*) may be large or small, the former seen in larvae living in extremely dilute solutions (Fig. 13.1).



▲ **Fig. 13.1** *Larva of Culex showing differences in size of the anal papillae in distilled water and in salt water (R.F. Chapman, 1969)*

Insects living in salt water possess a haemolymph hypotonic to the medium. The salts are excreted with urine, but are drawn back into the rectal fluid, which is hypertonic to haemolymph.

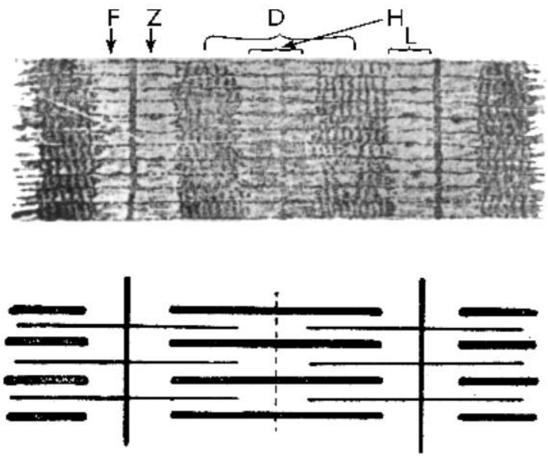
◆ Chapter 14

Muscular System

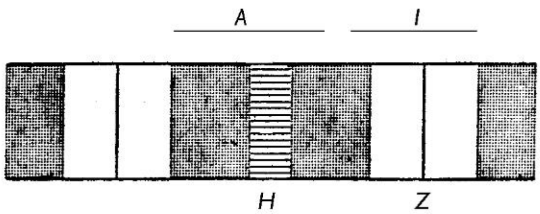
As in vertebrates the insect muscles are also grouped into the striated, non-striated or smooth and cardiac muscles. With respect to their function they are recognised as phasic and tonic muscles. The former are muscles with a point of origin and insertion, fixed directly into the parts of the legs or on apodemes. The latter are muscles without definite points of origin and insertion, often inserted on the same muscle and capable generally of spontaneous and rhythmic contraction. The muscles are mostly striated and are made up of multinuclear fibres made up of myofibrils with alternating dark and light staining segments. As in vertebrates, the muscle fibres are covered by a tough sheath, the sarcolemma. The muscles are disposed of in bundles of fibres called fasciculi. The covering of the muscle bundle is termed the epimysin while that of a fibre as perimysin. Fibrils or fibrillae make up the fibres and these fibrils lie in the sarcoplasm which is the protoplasm of the muscle. The thin myofibrils (Fig. 14.1) in the sarcoplasm always lie in contact with the mitochondria or sarcosomes. The fibrils are composed of two protein molecular filaments called myosin and actin. Myosin filaments are stout, elongate structures with heads at one end, and in each muscle bit (sarcomere) all myosin molecules of one half will be along one direction and in the other half in the opposite direction. Each muscle filament is surrounded by six actin filaments unconnected in the middle.

The muscle bundle appears striated transversely, these form the Z-discs. On either side of the Z-disc is a less dense area, this is the sarcomere or muscle bit. Projecting from the two Z-dics into the unstriated area are the peripheral actin filaments which do not meet in the middle, within which lie the myosin threads which do not, however, reach the Z-discs. This produces a darkly stainable area in the middle which is isotropic (1) and lightly stainable lateral areas, the anisotropic (A) bands (Fig. 14.2) The A band itself is paler in the centre forming the H zone. So a muscle segment appears to be as in the diagram between two Z-discs.

This pattern characteristic of vertebrates is applicable to insect muscles also. However, in insects the material is more birefringent and viscous indicating a more pronounced fibrous nature.



▲ **Fig. 14.1** *Muscle as seen under the electron microscope. Diagram of the arrangement of filaments shown above. D-Dark disc, L-light disc, F-Fibrilla, H-median disc, Z-Telophragma or Z-line (R.L. Patton)*



▲ **Fig. 14.2** *Muscle fibril showing the H zone (middle striped), the A band with the H zone and the lateral areas, and the I bands with the unshaded regions vertically showing the Z-line.*

The muscles contract on receiving stimuli from the nerve impulse. The nerve impulse changes the permeability of the muscle membrane resulting in a rushing in of sodium ions raising the potential inside. This leads to the flowing out of potassium ions to restore the original condition. This short term rise is the postsynaptic potential, which helps in the release of calcium ions in the muscle. The rest of the physiological pathway is not properly understood. ATPase gets formed converting ATP into ADP and releasing energy for contraction. The sarcomere shortens by the sliding of actin and myosin filaments. ATPase activity stops as calcium ions fail to emerge.

In insects fast and slow axons are recognised, the fast ones stimulating postsynaptic potential of a constant size.

Fuels that keep the muscles active are glycogen and fat, of which the latter is more important. Usually glycogen initiates muscular contraction (as in locusts) which will then continue with fat supplies. The rates of oxygen consumption are high in insects, as much as 400 litres O_2/kg/hr. The ventilation of wing bearing segments aids in this consumption of oxygen directly by the cells. Sometimes, the muscles are attached by fibrillar non-striated structures called tonofibrils which often extend to the procuticle.

Fundamentally, the insect muscles are classified into the somatic muscles acting on the skeleton and the appendages, and the visceral or splanchnic muscles acting on the internal organs. Somatic muscles are mostly arranged in pairs and have distinct points of origin and insertion while the splanchnic muscles are not arranged in a symmetrical fashion.

The generalised arrangement of muscles in an insect includes (a) the cervical muscles, muscles of the mouthparts and those of the antennae comprising the main cephalic muscles, and (b) the longitudinal tergal and sternal muscles, the lateral muscles extending between the terga and the sterna (tergo-sternals or tergo-pleurals or sterno-pleurals), and the transverse muscles often found in the thorax and the abdomen.

In a thoracic segment there are also muscles, extrinsic and intrinsic leg muscles as well as the muscles of flight. The flight muscles of insects are of interest, in that they possess characters different from the skeletal and locomotor muscles. The phasic muscles usually provide the power for wing beat (often over 1000 wing-beats per second and the tonic muscles serve to keep the wing articulation in place. The high frequency of the wing beat is not brought about by stimulation and contraction due to the resilient properties of the muscles concerned. Insects which are poor fliers have the muscles of the nonfibrillar type.

Muscle fibrils contain numerous mitochondria. A well developed relationship between mitochondria and the muscles of flight is seen in orders like Diptera, Hymenoptera and Coleoptera. These muscles exhibit an excellent condition for linking catabolism of carbohydrates with production of ATP involving aerobic mechanisms unlike in mammals. Mitochondria are believed to produce the relaxing factors in insects.

◆ Chapter 15

Insect Movements

Movements in insects occur to find food, to effect dispersal and to reproduce. Terrestrial locomotion involves walking, creeping, jumping and running while aquatic forms swim or float or wriggle; most insects can also fly. In all of these movements the legs, wings, and specialised organs play a major role.

The legs perform various types of walking movements to raise, depress, extend, or flex the body or its parts over the ground. The coxa is the principal region involved in specifically deciding the type of movement. Muscles which lie within the leg or outside the leg produce the movements. The coxal musculature comprises pairs of antagonistic bundles.

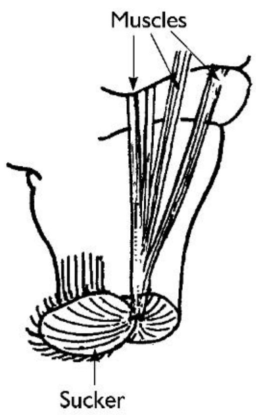
Mechanically the leg acts like a strut or like a lever. Additionally muscular activity plays a role in exerting forces and effecting movements. In walking, the legs move in a well-defined sequence. The hind leg is the trigger for leg movement and within a segment, the two legs move alternately. In *Periplaneta,* during slow walk the order of protraction of the legs (L for left: R for right) is R_3 R_2 R_1 L_3, L_2, L_1. At higher speeds the order is changed to L_1 R_2 L_3 R_1 L_2, R_3 and the legs move in rapid succession. Generally this sequence is usual in insects with only a few exceptions. The speed of movement is variable, especially as temperature rises. At 25° C *Periplaneta* runs at about 70 cm/sec which may extend up to 130 cm/sec.

Jumping involves adaptation of hind legs as in orthopteroid insects, Homoptera and Siphonaptera. This is mostly an escape mechanism. In orthopteroids, the movement is fuelled by power from the large extensor tibial muscles lying within the femur. Each foot exerts a thrust of about 20 g against the ground. In jumping Homoptera the movement results from well developed muscles from the femora, pleuron and a notum attached to the trochanter. Fleas jump using femoral muscles arising from the thorax.

Collembola do not use their legs for jumping but employ devices on the abdomen. From the hind end of the fourth segment are the furcula which are turned inwards and held bent with a retinaculum of the third segment. Sudden release of the furcula from the retinaculum results in the release of the springtail up into the air. Extensions of furcula show variation in different Collembola.

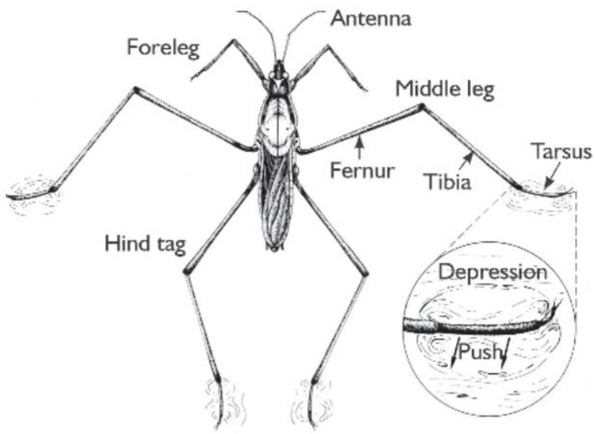
The click (elaterid) beetles and larval Diptera also can jump. When placed on their back, elaterids jump clicking the pronotum and the wing margin by sudden contraction of the muscles straightening the animal. Jumping in *Bactrocera* is by bending the back of the head beneath the abdomen and suddenly releasing the catch, and in cecidomyiid larvae a specialised, chitinised thoracic ridge or spatula holds the anal hooks at the body tip and releases suddenly.

Crawling movements are exhibited by various larvae. This movement is accompanied by change in body shape. Blood pressure within the body provides a hydrostatic skeleton. Muscles line the body wall keeping the body rigid. Fluid pressure can change the body shape as in caterpillars. Movement on the ground is with the help of thoracic legs and the abdominal prolegs. Bearing armed hooks, the plantar surface of prolegs can exert a grip when the leg is evaginated by liquid pressure and then the intrinsic muscles contract, creating a tiny surface of vacuum–it works like a sucker (Fig. 15.1). Crawling in caterpillars takes place by undulating contractions postero-anteriorly. Variety of structures involved in locomotion of slug caterpillars include thoracic legs, abdominal prolegs or suckers, and spinnerets, and additional legs with prolegs which increase their ventral surface contact with the substrate. Ventral adhesion is increased by the spinneret both in laying down wet silk and in cleaning debris off the ventrum. In legless maggots seta bearing muscular pads, arranged in linear rows, help in crawling.



▲ **Fig. 15.1** *Proleg of a caterpillar with muscles and setae (Snodgrass, 1935)*

Podura (Collembola) moves over water surface with the help of waterproof body surface and holding on to the surface by the anchoring action of ventral tube of first segment of the abdomen. They can jump on water surface like the Collembola on land. The beetle *Stenus* also can walk on water surface slowly; it produces a secretion from the hind end which on contact with water will reduce surface tension, and the animal in front is drawn forwards into the region of the higher tension. The bug *Gerris* stands on the water surface and with the two pairs of hind legs it can paddle (Fig. 15.2).



▲ **Fig. 15.2** *Two pairs of hindlegs of water strider adapted for paddling on water surface. Right bottom: Enlargement show tarsal region of leg does not break the surface film (Illustration by Jennifer Armstrong, D.M, Calabrese, 1990)*

Many aquatic insects are free swimming and some are bottom living. In free swimming insects like larval and adult Heteroptera, beetles, and larval and pupal Diptera, swimming is aided by hind legs, occasionally supplemented by middle legs. Tibiae and tarsi in such cases are flattened and bear stiff hairs or cuticular blades. Many free swimming insects are buoyant, stored air within the body helping in floating when at rest. The head usually dips down when swimming, cleaving water downwards; when held up, the insect too tends to rise. A downward thrust is developed by the retracting leg. In the submerged animal its protraction also aids in producing forces. Most aquatic insects are streamlined and depressed, offering minimum resistance in cutting through water, and stability in the rolling and pitching planes. Swimming rates vary; *Gyrinus* swims up to 100 cm/ sec when under water. Undulating movements are employed in swimming in *Ceratopogon*, while caudal filaments in ephemerid nymphs aid in spurt-like movements. Mosquito larvae have a density very close to that of water, but wriggle about using posterior hair fans; when not wriggling they surface.

Bottom-living forms like the odanate larvae, Trichoptera and *Aphelocheirus* walk on the ground under water. They, however, do this slowly with an awkward gait. Sudden escape movements are exhibited by Anisoptera larvae by ejection of water from the branchial basket. The contractile movement of about 0.1 second forces water through the rectum at a velocity of 250 cm/sec driving the larva forwards at 30-50 cm/sec.

Flying is exhibited by a wide majority of insects where well developed wings are present. The up and down movements of wings are due to the direct and the indirect wing muscles, besides thoracic elasticity and the wing base.

The upward movement of the wing is due to the contraction of the dorso-ventral thoracic muscle drawing the tergum downwards and the wing base placed on the pleural process throws up the wing. The pleural process acts as a fulcrum. The downstroke of the wing is due to the contraction of the direct basalar muscle inserted into the basalar region of the wing. In Hymenoptera and in flies, the long indirect muscle contracts, arching up the tergum and flapping down the wings. Elasticity of the wing hinge which contains resilin pads also helps in minimising expenditure of energy for flight.

The frequency of wing beat varies with insects. In the butterflies it is 5-20/sec, in *Apis* 190/sec, and in the fly *Forcipomyia* 1000/sec.

The movement of the wings keep the insect airborne and moves it along. The relative wind applies force on the wings comprising the lift and the thrust. The lift is the horizontal force propelling it forwards. The thrust must be sufficient to overcome the drag resulting from the insect's profile and the development of vortices at the wing tip.

The forces acting on insects during flight vary and may thus be responsible for instability. It may involve rolling (rotation along long axis of body), rotation (along the horizontal axis) and yawing (along the vertical axis). Various sensillae perceive these instabilities which will induce the correction of these to maintain a steady flight. In this connection, halteres of Diptera are of special interest. They vibrate with the same frequency as the wings but in antiphase.

When flying the legs are kept close to the body, but just before alighting, they are extended and the insect lands on its feet. Visual cues help considerably in landing.

Flight in insects is dependant on several factors. Light, wind speed, humidity and temperature exert limiting influences. Internal factors like body temperature of the insect, development of muscle and the available fuel, feeding activities and reproductive status (like gravid) are also limiting in nature.

The stimuli that promote take off-will comprise visual ones and light, favourable wind speed, increase in humidity, favourable olfactory hints especially in blood sucking forms, slight increase in temperature, disturbance to the animal, etc.

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◆ Chapter 16

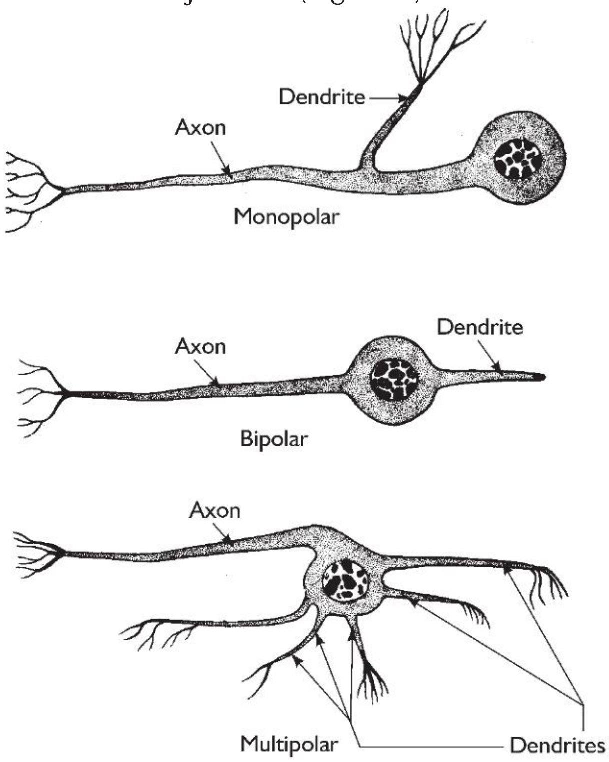
Nervous System

Living organisms always respond to stimuli and as in higher animals, the nervous system of insects serves to perceive and transmit stimuli or impulses from one part of the body to another and is made up of neurons or nerve cells. A neuron is a specialised ectodermal cell consisting of a cell body with a nucleus, a long filament or axon with lateral branches and one or more branched processes, the dendron or dendrites arising from the cell. The dendrites transmit impulses towards the central cell body, while the axon transmits them away from it. Only one axon is present in a cell, but it may have several dendrites. The meeting place of the axon of one neuron with the dendrites of another is termed a synapse. The environmental stimuli are identified by groups of neurons called the ganglia, each with a central mass being called a neuropile. Nerves differ in shape and functionally may be grouped into the sensory, motor, association, or connecting nerves. Neurons lying in the hypodermis conducting impulses from a sensory organ inwards are termed sensory, while those lying in the central nervous system and conducting impulses anteriorwards to muscles or glands are termed motor neurons. Association neurons serve to transmit the sensory to the motor impulses. According to the number of axons, the neurons are classified into unipolar, bipolar and multipolar neurons. The nerve fibres include a large number of axons or dendrites bound together by one or more sheaths of connective tissue–the outer neurilemma and the inner myelin sheath.

Histologically the nervous system may be described to have the following distinguishable parts:

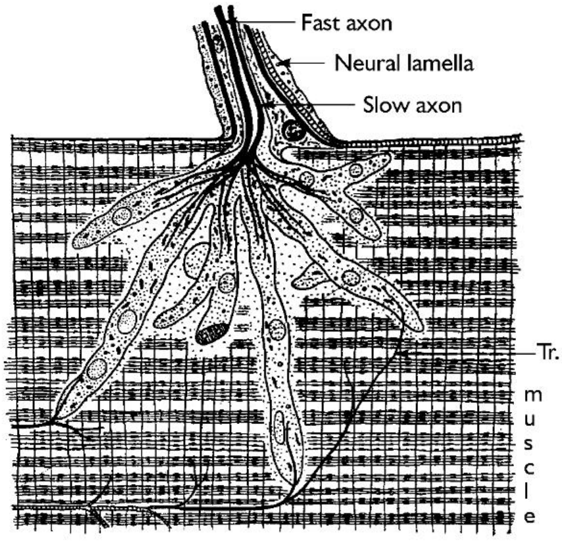
- The sheath forming a non-neural region comprising a non-cellular intimate perineurium. Neural lamella provides support and the perineurium affords passage of organic material.

- One or more cells form an envelope around each neuron, these are the glia cells. Glia cells allow transfer of nutriments. Among the glia cells are materials which may be mucopolysaccharides.
- The neurons proper which have well defined and nucleated cell bodies called perikarya. This region has an abundance of mitochondria, ribosomes and dictyosomes. Neurons have axons emanating from them. Cells with single axons (monopolar), double processes (bipolar) and several branches (multipolar) are present (Fig. 16.1).
- The mass of axons form the neuropile. Here most of the synapses occur.
- Where two neurons come together is the synapse, usually with a film-like gap separating the two. Usually synapse is with several bodies called synaptic vesicles. Mitochondria are abundant, and glia cells are wanting in this region.
- The motor-nerve supply to the muscle shows a multiple contact with the tissue. This is the nerve muscle junction (Fig. 16.2).



▲ **Fig. 16.1** *Monopolar, bipolar and multipolar neurons (R.F. Chapman, 1969)*

The nervous system is intimately associated with the muscular system, to form the neuromuscular system, the nerves providing the transmitted stimulus and the muscles responding to the stimulus by contraction. In insects, neuromuscular transmission is effected through the neuromuscular junction which unlike in vertebrates is provided with a series of endings or end plates arranged over the muscle fibre at several places. Further, the fibre is supplied with double nerve endings known as slow and fast axons. The membrane of the axon intimately contacts the muscle membrane and synaptic vesicles are present.

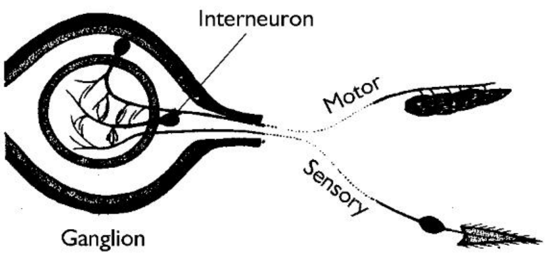


▲ **Fig. 16.2** *Nerve muscle junction (R.L. Patton)*

Transmission of nerve impulses is explained by the ionic hypothesis. The concentrations of inorganic ions in the medium around the neuron and within the neuron bring about excitable conditions in the nerve cell which are progressively transmitted along the nerve as electrical, measurable responses. The neural envelope has an important role in this event.

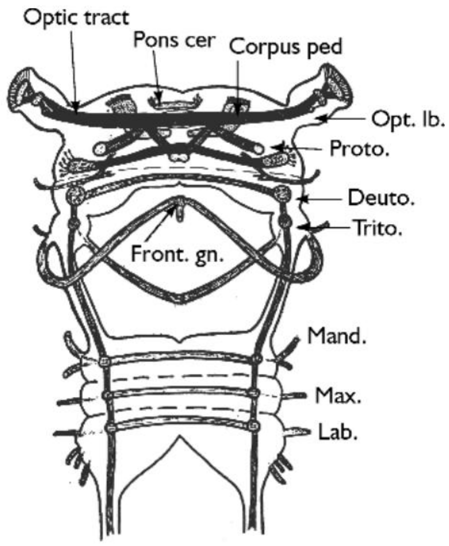
In the neuromuscular junction, this initiation will result in a release of transmitter chemical substances from the synaptic region. This occurs in vertebrates and insects, but in the former acetylcholine has been identified as the transmitter substance, in insects cholinergic transmission has not been proved. The slow axons bring about a slow mechanical response, the peak tension attained by providing up to 80 stimuli/second. The fast axons require only 10 stimuli/second to reach this tension. A graded response has become possible by a distribution of the fast and slow axons, in specialised situations as in the locust legs. The neuromuscular mechanisms in flight muscles (using beat frequencies of over 1000/second) is not fully understood.

The synapse is the important unit of the functional nervous system. The nervous system from the functional point of view may be said to have three elements: (i) sensory axon at receiving end, (ii) the inter-neurons within the central nervous system, and (iii) the motor neuron (Fig. 16.3) to the end organ. Fig. 16.3. This has a similarity in organisation to the reflex arc in vertebrate series. While there is a lack of information on several points, the physiology of the sequence of events in insects may be more or less as in the vertebrates. The insectan interneuron is more complex and suggests wide coverage that in vertebrates would require several neurons.

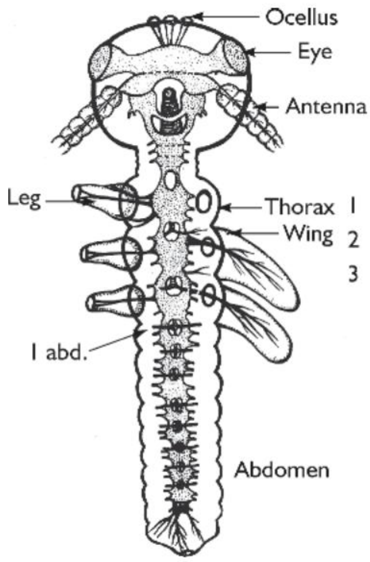


▲ **Fig. 16.3** *Components of the central nervous system*

As in the vertebrates, the insect nervous system is also usually divided into the central nervous system and the visceral nervous system. The former comprises the brain, suboesophageal ganglia and ventral nerve cord. It is made up of paired ganglia (Fig. 16.4) connected by longitudinal connectives and transverse fibres or commissures. It has already been mentioned, that each body segment has a pair of ganglia (Fig. 16.5). The ganglia of the mandibular, maxillary and labial segments become fused to form the suboesophageal ganglion. The brain which is also a concentration of ganglia, is formed by the fused ganglia, of the optic segment, the protocerebrum, the antennary segment or deutocerebrum and those of the intercalary segment or the tritocerebrum. The thoracic and abdominal ganglia which follow may undergo fusion in a variety of ways in different insects. All the thoracic ganglia may become fused or the first abdominal ganglion might fuse with the metathoracic ganglion or as in the case of some Diptera and many Hemiptera all the thoracic and abdominal ganglia may become fused to form a single compact unit.



▲ **Fig. 16.4** *Diagram of the organisation of the nervous system of the insect head, corpus ped - corpus pendunculata, opt. lb - optic lobe, proto - protocerebrum, deuto - deutocerebrum, trito - tritocerebrum, front. gn - frontal ganglion, mand - mandibular, max – maxillary, lab - labial segments.*



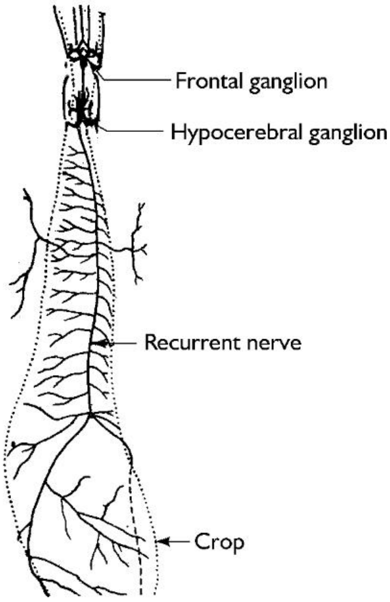
▲ **Fig. 16.5** *The general organisation of the nervous system of the insect, showing ganglia (after Kaestner)*

The Brain

The protocerebrum includes the protocerebral lobes and the optic lobes. It is a bilobed ganglion, connected internally by a transverse commissure, the central body. Also situated in this region is a peculiar structure comprising numerous fibres and called the mushroom body or corpora pedunculata. The optic lobes constitute a complex region with several tracts of nerve fibres, whose complexity is correlated with the degree of development of the eyes. The optic nerves leading to the compound eyes emerge from this region, as also the ocellar lobes and ocellar nerves. The deutocerebrum consisting of paired ganglia of the antennary segment, is made up of partly fused halves or lobes, from which arise the lateral antennary lobes. The tritocerebrum also consists of two widely separated lobes connected by a transverse commissure, which loops back below the oesophagus to form the suboesophageal commissure. The nervous system is not only a relay station between receptors and effectors, it also aids in integration. Work on the integration centers have, however, been meagre. The corpora pedunculata especially is important in this respect. Controlling behaviour and regulation of intersegmental activities, singing behaviour, etc. have been ascribed to this centre. Adaptive changes in behaviour of an individual, involving neural mechanisms have been called learning. Habituation (learning to ignore insignificant stimuli), conditioning (responding to repeated stimuli), trial and error learning, recognition of features in homing, etc. are known in insects. These activities have been said to be controlled by the corpora pedunculata; the development of this part appears to be directly proportional to the increased ability to learn on the part of the insects. Removal or damage to this area detrimentally affects the learning abilities. However, headless insects also show an ability to learn (*Schistocerca*) and this has been attributed to the segmental ganglia.

While the peripheral nervous system includes nerves arising mostly from the ganglia of the central nervous system, the sympathetic or visceral nervous system includes the stomatogastric or oesophageal nervous system, the ventral sympathetic system associated with the ganglia of the ventral nerve cord and the caudal sympathetic system arising from the last abdominal ganglia and supplying the reproductive systems and the posterior end of the gut. The stomatogastric system is connected with the brain and supplies the fore- and midintestine, and the heart. The frontal ganglion associated with this part of the nervous system lies in front of the brain, above the oesophagus. The frontal ganglion gives off posteriorly, the recurrent nerve, which expands into the hypocerebral ganglion beneath the brain (Fig. 16.6).

From this, the usually paired recurrent nerve arises and supplies the ventral part of the foregut and ends in a stomachic ganglion. Closely associated with the hypocerebral ganglion and connected with it, are the paired oesophageal or pharyngeal ganglia, also called corpora cardiaca, and more laterally placed corpora allata.



▲ **Fig. 16.6** *Stomatogastric system of the cockroach (after Willey)*

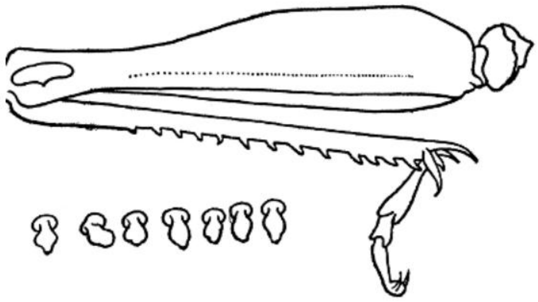
It was mentioned earlier that the neurons are discontinuous, the terminal branches of one axon interlacing with those of another, forming the synapse. Any stimulation causes the release of some chemical substance like acetylcholine and it is this substance that triggers further activity in the next or adjacent neuron. A nervous system thus depends on acetylcholine for impulse transmission or for conduction between neurons is termed a cholinergic system.

◆ Chapter 17

Sonification

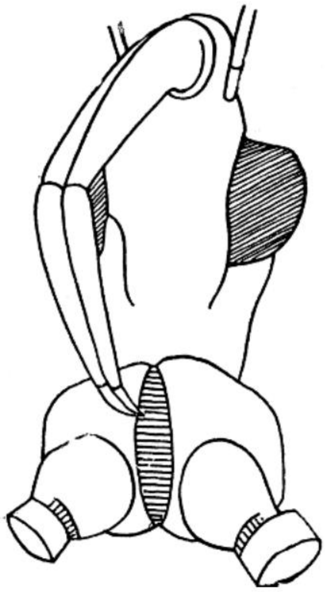
Many insects produce sound employing a variety of mechanisms. Continuous wing vibrations or intermittent noises will constitute sounds of insects–a train of sound waves forming a pulse, and a sequence of pulses a phrase. Sounds may arise as a by-product of another activity, like forcible contact of a part of body to a substratum, frictional rubbing sounds, vibrating membranes and by forcing of air stream. When wings beat, sounds are often produced, quite audible ones are those of *Apis* at 250 wing-beats/sec and of mosquito *Culex* 280-340 wing-beats/sec, and of *Schistocerca* 60-6400 wing-beats/sec. Termites produce sounds by striking the substratum with hardened parts of body-like jaws, top of the head, etc. Most insects produce sounds by rubbing roughened region of a part of the body against another. A ridge or rough file forms the strigil and the scraper forms the plectrum. Moving the plectrum over strigil produces a vibration of the membrane carrying it. Elytral stridulation occurs in crickets, and femoro-elytral (femur and elytra) stridulation in acridoids (Fig. 17.1). These occur in males. In some Hemiptera the tip of the rostrum rubs against (Fig. 17.2) a sternal file. Elytral rubs produce sound in Coleoptera. Larval passalids stridulate (Fig. 17.3) using coxal ridges on midlegs as a file worked on by a scraper in the trochanter of the last leg that has become non-locomotor and is only stridulatory. Lepidopterous pupae like those of *Gangara* has a pair of ridges on either side of the fifth abdominal segment against which the long proboscis rattles to produce a hiss.

Sounds which arise from the vibration of the cuticular membrane occur in Homoptera. This normally occurs in males (occasionally in females). The cuticular membrane with hardened rim forming a tymbal provided with a fibrillar muscle and arched over an air sac is seen in the thorax of cicadas. Muscle contraction bends the tymbal, working like a tin



▲ **Fig. 17.1** *Femoral stridulatory pegs of an acridoid (R.F. Chapman, 1969)*

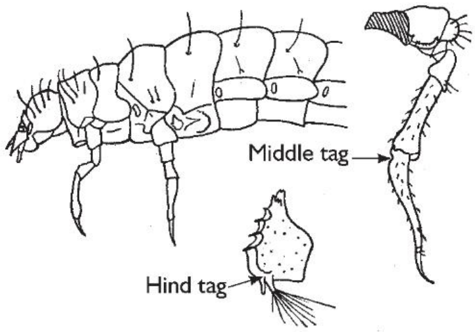
plate in producing a click. The tymbals of either side work synchronously. Tymbals also occur in cercopids, jassids and some pentatomids. Vibrations of thoracic sclerite produce the piping sound of virgin queen bees. In the moth *Acherontia* air is sucked through the proboscis by enlarging the pharynx producing vibration of epipharynx, which results in a whistling sound.



▲ **Fig. 17.2** *Hemipteran stridulatory structures (ibid)*

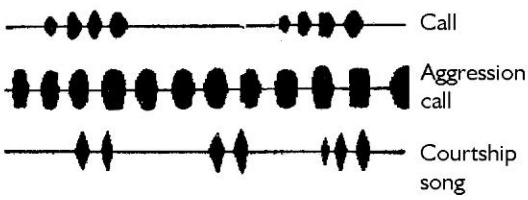
The sounds produced by insects serves various functions. They may have an extra specific function as in sound mimicry or warning stridulation, but this is rare. Most of the sounds are of value in communicating between members of the same species. In

Orthoptera, Heteroptera and cicadas, the sound is of significance in courtship. In *Gryllus*, calling, aggression, courtship and copulation songs have been recognized (Fig. 17.4). The male of *Aedes* responds to flight song of the female. In *Oecanthus*, a male territory of 50 sq cm



▲ **Fig. 17.3** *Stridulatory organs of the larva of Passalus (ibid)*

will be occupied and the insect sings characteristically. An intruding male cricket evokes an aggressive song from the male, leading to fighting and flight by the intruder. Larval passalids also show an aggressive type of stridulation. In social and semi-social insects sounds are employed in communication, as in *Apis*. Sounds produced by *Zootermopsis* warns other members of the colony driving members to more remote parts, thus forming an alarm call. Generally speaking, sound production helps in aggregation of species.



▲ **Fig. 17.4** *Oscillogram of calls of the cricket (ibid)*

Light and temperature affect sonification. Increase in temperature increases the pulse rate of the sound. Internal factors like tactile stimuli, maturity of gonads, responsiveness of the female, etc. are important factors which have been recognised.

Control of sound production is primarily neural and in forms like *Achaeta* the presence of a sonification centre has been suggested in the mesothoracic ganglion.

However, closely related species, which will also interbreed have, specific sonification patterns. Three species of *Megacicada (M. tredecim, M. tredecula* and *M. tradecassini)* which inhabit the same area in North America have characteristic sound producing patterns, and the singing in chorus by individuals also show specific differences in the timing of songs during the day. This has been a successful sexual identification tool.

◆ Chapter 18

Sensory Receptors

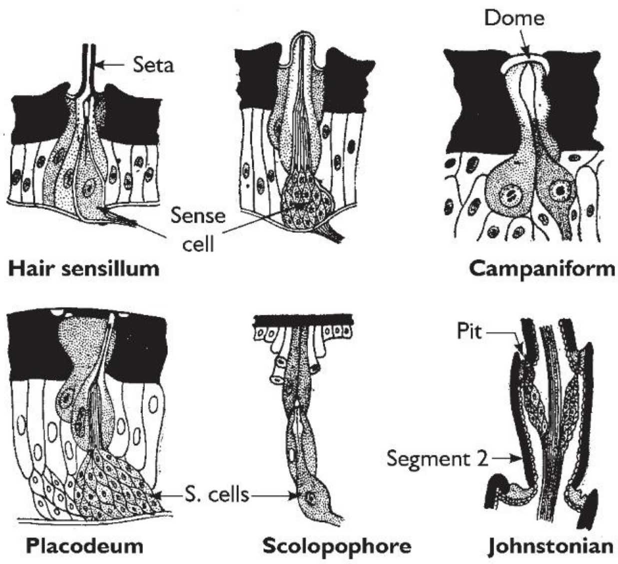
Sensory receptors are primarily responsible for converting stimuli such as sound, vibrations, change of pressure of medium, chemicals involving taste, smell, or optic or light into nerve impulses. In other words, the receptor organs are mainly responsible for the reception of external stimuli and passing them on to the neuro-muscular system, resulting in the varied behaviour patterns of insects. Broadly, the receptors are classified into those which perceive external stimuli (exteroceptors) and those which perceive internal stimuli arising from within the body (interoceptors). The latter also include organs which contribute to the maintenance of equilibrium and are called proprioceptors. According to the various stimuli perceived, they are classified into mechanoreceptors, phono or auditory receptors, chemoreceptors, temperature and humidity receptors, and visual or photoreceptors. Basically the cell or a group of cells making up a receptor is called the sensillum which is only an innervated hair or seta having a direct contact with the sensory cell. It may undergo several modifications according to the nature of receptors. They are categorized follows:

- Sensilla trichoidea: The sensillum which has seta-like external process.
- Sensilla chaetica: The sensillum which has spine-like process.
- Sensilla squamiformia: The sensillum which has scale-like process.
- Sensilla basiconica: The sensillum which has peg-like process.
- Sensilla coeloconica: The sensillum which is sunk in a pit.

Whenever the external process becomes lost or is not developed, it may develop a thickened dome-like covering of the cuticle (sensilla campaniformia) or a mere plate (sensilla placodia). When the sensory cell has no process as in the above cases but becomes connected with two specialised cells, the distal one develops rod-like structures called the scolopale or scolops and the sensilla is termed sensilla scolopophora. The sensillae concerned with the detection of light are called the sensilla optica of the eyes.

Mechanoreceptors

These respond to the sense of touch or are tactile receptors and often act as proprioceptors serving to maintain bodily posture or equilibrium. These receptors may be in the form of (a) sensory hairs distributed all over the surface of the body, antennae, tarsi and other organs of touch (Fig. 18.1), and (b) groups of spindle-like bundles or specialised sensillar or scolopophores each containing the sensory rod—the scolopale. These groups are termed chordotonals (Fig. 18.2) or scoloparia. As is normal for seta, they also have trichogen and tormogen cells, secreting the hair and its sockets, or a campaniform sensilla occurring on wings, appendages, cerci, etc. When Scoloparia on palps and legs, they act as proprioceptors. These serve for the perception of internal pressure changes and detect mechanical vibrations and external strains, particularly at the base of the wings. Basally the scolopophore has an envelope cell and a cap cell enclosing within it the axial nerve fibre or chordotonal nerve. The sensory rod or scolopale develops within the envelope cell and at the base of the envelope cell is a fluid-filled vacuole with which the scolopale is connected. Its apex ends in a knob. In ants the subgenal organs are sensitive to vibrations of the ground.



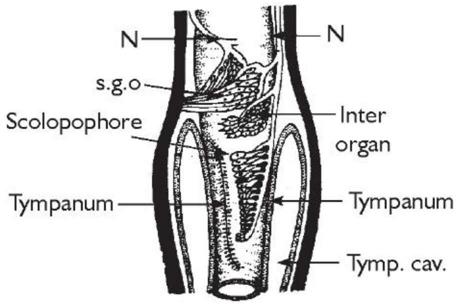
▲ **Fig. 18.1** *Sensory organs of various insects—diagrammatic (Snodgrass,1935)*

Located on the second antennal segment is a type of chordotonal organ called the Johnston's organ. It consists of bundles of radially arranged sensillae, attached on one end to the intersegmental membrane between the second and third antennal segments and at the other end to the walls of the antenna. They are variously developed in different insects and act as proprioceptors and also serve to detect air currents, vibrations on water surface, etc.

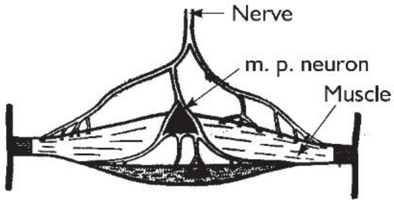
Organs of equilibration helping in the normal orientation are developed in several insects. In water-scorpions this is achieved through special pressure receptors, developed in association with certain abdominal sterna, that respond to slightest changes in pressure. The halteres in Diptera contain several sensillae which maintain stability in flight. Statocysts are present in some insects like the metathoracic organ in the hymenopteran *Dorymyrmex*, and cephalic Palmen's organ in ephemerids, and probably Hagemann's organ of *Corixa*. Multipolar neurons possessing free ends comprise stretch receptors. They are associated with muscles or connective tissue (Fig. 18.3). They occur in orthopteroids, lepidopterous larvae, Trichoptera and Neuroptera. They respond to changes in one part of the body with another, where a stretch is involved.

Auditory Organs

They help in the detection of sound vibrations transmitted by the tympanic membrane and cause corresponding vibration of the hairs of the tactile sensillae. They differ from mechanoreceptors only in that they respond to lower intensity vibrations. The auditory receptors are usually found in the auditory hairs characteristic of the anal cerci of crickets and cockroaches, which carry well developed innervated hairs. The hair sensilla of caterpillars also act as auditory receptors. Tympanal organs are well developed structures often consisting of a thin stretched cuticular membrane in connection with the tracheal air-sacs. Attached to the membrane or to the walls of the tracheal sacs are groups of chordotonal sensillae. In the short-horned grasshoppers, the tympanal organs are situated on each side of the first abdominal tergum while they are at the base of the foretibia in the long-horned grasshoppers and crickets. They may also be present on either side of the mesothorax in association with the spiracle in some aquatic insects or at the sides of the metathorax and at the base of the abdomen of some Lepidoptera. A complex tympanal organ such as those of crickets and long-horned grasshoppers (Fig. 18.2) consists of a slit-like aperture at the base of the foretibia leading into a cavity lined with thin cuticle. An enlarged trachea enters the tibia and its walls are located close to the inner walls of the cavities. Placed at the base of the tympanal chamber are supratympanal organs consisting of groups of large numbers of scolophores innervated by sensory nerve fibres arising from the prothoracic



▲ **Fig. 18.2** *Chordotonal organ-diagrammatic (ibid)*



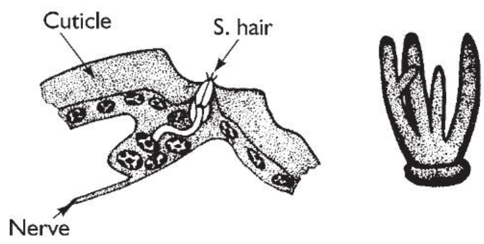
▲ **Fig. 18.3** *Stretch receptor (R.F. Chapman, 1969)*

ganglion. Two more sensory structures are also associated with auditory receptions, namely the intermediate organ placed at the base of the tympanal chamber and the crista acoustica or Siebold's organs made up of a series of scolopophores attached to the walls of the trachea. Noctuids have ears which can locate high frequency sound; sounds emitted by bats as short pulses (0.5 cycles/second long) with intervals of 5 cycle/second and varying from 30 kilocycle/second to 100 kilocycles/second are perceived by the insects.

Chemoreceptors

Chemoreception is developed to a remarkable degree in insects particularly, those of the taste or gustatory sense, of smell or olfactory sense and senses responding to common chemical stimuli. The olfactory receptors may take the form of setae supplied with nerves and placed in depressions (sensilla trichoideum olfactorium) or trichoid sensillae generally found on the antennae, mouthparts and tarsi. Sometimes the receptors are peg or comb-like occurring mostly on the antennae and palp and are called basiconic sensillae. In other rare cases, sensillae are situated more deeply below the surface (sensilla coeloconicum) and when they lie in a deep coecal cup and are connected to the surface by a tube, they are called sensillae ampullaceus. When the sensilla is an ovoid, circular plate, it is called placoid or sensilla placodium. Gustatory receptors are found at the tips of the palps and rarely on the antennae as in the honeybees and wasps and at the distal ends of the tibiae and tarsi seen especially in Lepidoptera, honeybees, etc. Usually these receptors consist of groups of thin walled hairs associated with large trichogen cells and the sense of taste has often been referred to as contact chemoreception. Besides being of great value in feeding and its control, contact chemoreception is also significant in the control of egg laying. Chemoreceptive selectivity helps in choosing sites of oviposition.

There is a common body chemical sense also in insects, helping them to avoid irritant substances (like acids, secretions) in the environment; the receptors have been suggested in some cases to be peg sensillae.

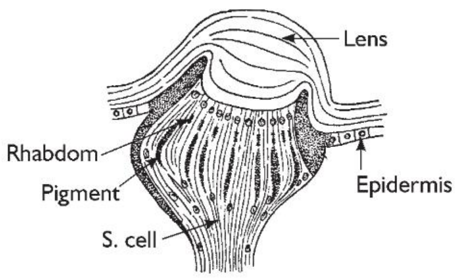


▲ **Fig. 18.4** *Humidity receptors. On the left from the antenna of Pediculus, on the right from the antenna of Tribolium (ibid)*

Insects respond to changes in humidity (to water vapour) and humidity receptors have been found on the antennae of *Tribolium* (Fig. 18.4), *Pediculus*, etc. In the former they are the thin walled, branched pegs, and in the latter they form sensory hair organs. The working of these organs is not clearly understood.

Eyes of Insects

The eyes or photoreceptors of insects include the simple eyes or ocelli placed dorsally and the compound eyes placed laterally on the head. The ocelli are named according to their disposition as the dorsal and the lateral ocelli. Structurally the ocelli and compound eyes are not fundamentally different, the most obvious distinction being that only a single corneal lens occurs in an ocellus and many in compound eyes. The dorsal ocelli (Fig. 18.5) are usually three in number, arranged in a triangular fashion mostly between the compound eyes or on the vertex or the frontal region of the head. They are usually absent in cockroaches. Each ocellus has a biconvex lens beneath which is a transparent corneagen layer. The cornea may be a simple dome-like covering on the eye, but it is mostly thickened to form a strong biconvex lens. The corneagen layer overlies the sensory elements which constitute the retinulae. A retinula is composed of visual cells or sensory (S) cells. Rhabdoms are produced by adjacent retinal cells or visual cells around a longitudinal



▲ **Fig. 18.5** *Dorsal ocellus (ibid)*

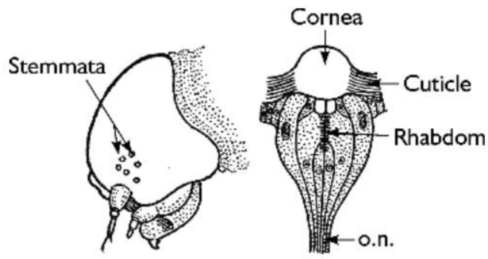
optic nerve, the rhabdom. Between the retinulae and around the margin of the lens there are usually pigment cells. The portion of the visual cells are continued as a fibre of the ocellar nerve.

The lateral ocelli are also referred to as stemmata (Fig. 18.6) and are present only in insect larvae and may occur singly or in groups as in caterpillars, on either side of the head. The number of the lateral ocelli in caterpillars is similar to that of an ommatidium of a compound eye.

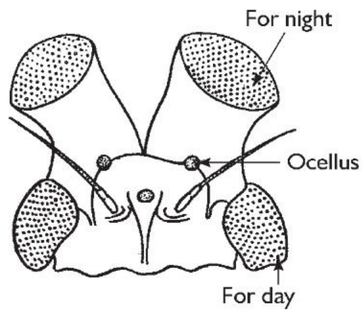
Usually, the compound eyes are the laterally placed cephalic photoreceptors. In some examples like trifilous gall midges, the two compound eyes meet and merge on the vertex of the head, so that the entire structure looks reniform. This is called the holoptic eye. In *Chloeon* (Fig. 18.7), *Bibio, Gyrinus* and some other examples, the faceted eyes show up as two distinctive regions on each side–one with small facets and the other with larger facets.

Typically each compound eye is built up of a large number of smaller units or ommatidia (Fig. 18.8), each ommatidium being externally bound by a facet or transparent cornea. Depending on the species the number of ommatidia varies from 1 to 10,000 in various insects.

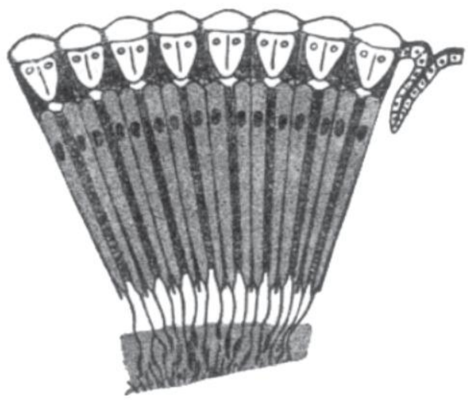
Each ommatidium consists of an outer light gathering (optical) and an inner light perceiving (sensory) part. The former comprises of a cuticular lens or cornea and a transparent cone underneath, secreted by the surrounding Semper's cells, and the latter is formed of a ring of sensory retinula cells and a central retractile rhabdom. The



▲ **Fig. 18.6** *Stemmata—from a caterpillar (Snodgrass, 1961)*



▲ **Fig. 18.7** *Head of Chloeon to show the compound eye divided into a terminal night eye and a basal day eye (adapted from Comstock, 'An introduction to Entomology')*



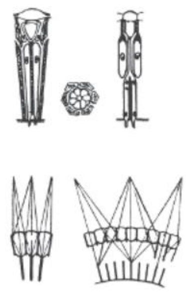
▲ **Fig. 18.8** *Part of a section of a compound eye to show the ommatidia (Snodgrass, 1935)* two regions are characterised by pigmented cells (outer primary iris cells and an inner secondary iris cells) to make each ommatidium light tight. This is the arrangement in eucone eyes. The compound eyes in insects show profound variation in structure and at least four major types may be recognised–eucone, pseudocone, acone and exocone types. The eucone type has a distinct crystalline cone and is commonly found in insects like ephemerids, Odonata, Lepidoptera, Hymenoptera, some Hemiptera and Coleoptera. The pseudocone type is characteristic of most Diptera, where the true crystalline cone is absent, the cone cells being filled with transparent semi-liquid material. Both the acone and exocone eyes lack the crystalline cone, either as a true cone or as a semiliquid body. In acone eyes, found in Dermaptera, most Hemiptera and Coleoptera, the cone cells are elongate and transparent, serving also as the corneagen layer. The exocone eyes as found in some families of Coleoptera, have a peculiar feature in that there is a deep cuticular ingrowth of cells beneath cornea proper, in addition to the cone layers. In some night-flying insects the retinular layer is supplied with colouring matter like erythrosin or xanthopsin serving to reflect the light entering the eyes and this structure is called the tapetum.

The insect eye could resolve two objects with an angular separation of 1°. This visual acuity is low at low light intensities. The sensitivity of the eye is dependant on the visual pigment and the nerve connections. Insects possessing two or more visual pigments can distinguish wavelengths; this colour vision occurs in many Hymenoptera, Diptera, Coleoptera, Heteroptera and Homoptera. The honeybee *Apis* can distinguish yellow, blue green, blue violet, ultraviolet and bee's purple (yellow and ultraviolet). Part of one compound eye may function as a region of colour vision as in *Notonecta.* Form, movement and distance perception have been found to be present in insects. The resolving power of the eye is directly dependant on the number of retinal photosensory units. The insects perceive a mosaic image. Schematising on certain premises which are physical, (Fig. 18.9) Mazokhiv Porshnyakov (1969)* has reproduced images as if

▲ **Fig. 18.9** *Mosaic image of a hawk moth caterpillar (Mazokhiv-Porshnyakov, Insect Vision, Plenum Press, New York, 1969)*

* Insect Vision (translated), Plenum Press, N.Y. pp. 1–306.

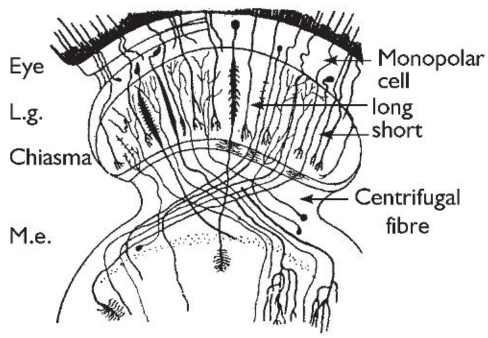
resolved by the insect. Eyes are recognised to fall into two functional groups depending on the comparative completeness of the light insulating pigment distribution. They are the apposition type where ommatidia form images side by side as a mosaic with the rhabdom extending full length and the superposition type where there is overlapping of images and with abbreviated rhabdom, this type being not completely light-tight (Fig. 18.10). The superposition eyes occur in crepuscular and nocturnal insects. During exposure to light there is a fall in sensitivity which is known as light adaptation, which recovers during darkness, this being called dark adaptation. In apposition eyes, there is seldom any movement of pigment in iris cells, and the recovery process is rather quick. In superposition eyes, there is an initial spurt of rapid recovery but soon it becomes slowed down.



▲ **Fig. 18.10** *Ommatidia: Diagram of apposition eye (above left) and superposition eye (above right) and diagram of pathways of light rays in apposition (left) and superposition (right) eyes. The nature of pigment cells around ommatidia are indicated in the two types of eyes (after R.L. Patton, Introductory Insect Physiology, Saunders Co.)*

In insects no optic nerve is present because the eye directly contacts the optic lobe of the brain. Three layers of ganglion–lamina ganglionaris, medulla externa and medulla interna—are clear and contain between them chiasmatic fibres. The complex pattern of crossing and connecting fibres are outlined in Fig. 18.11. Retinular cells bear nerves which contact the lamina ganglionaris and also probably medulla externa. Of the axons that develop synaptic contact with the optic lobes, short fibres that contact the lamina and long fibres that extend right through, have been recognised. The electrophysiology of the compound eye has not been extensively studied, and the physiology of vision from this angle has yet to be attempted. However, more definitive information on colour vision has been gathered.

Some insects possess what may be called a skin light sense, the body surface responding to light as in the larval *Tenebrio*, when all light receptors are occluded.



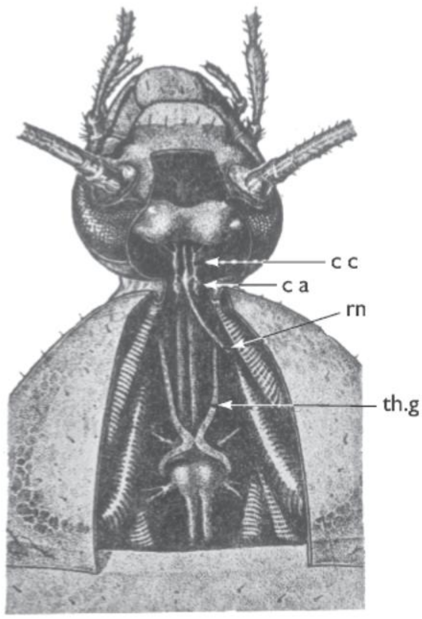
▲ **Fig. 18.11** *Structural complexity of the optic lobe of the honeybee (R.F. Chapman, 1969)*

◆ Chapter 19

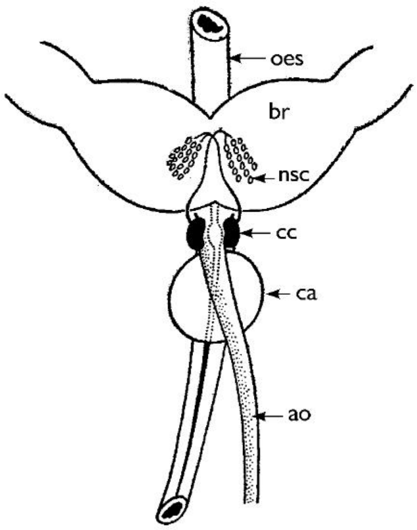
Endocrine System

The Endocrine System (Fig. 19.1) of an insect consists of the following:

- Neurosecretory cells. They are chiefly found in midregion of the brain and are composed of two or more distinct types of secretory neurons. Other variants are the lateral neurosecretory cells and neurosecretory cells of the ganglia.
- Corpora cardiaca. These are a pair of ganglia like glands lying in close association with the axons from the neurosecretory cells of the brain, and situated lateral to the aorta (Fig. 19.2).
- Corpora allata. A pair or two fused units of glands lying ventral to the anterior end of the aorta. (Fig. 19.2).
- A pair of central or thoracic glands. These are often situated in the prothoracic region of the insect.



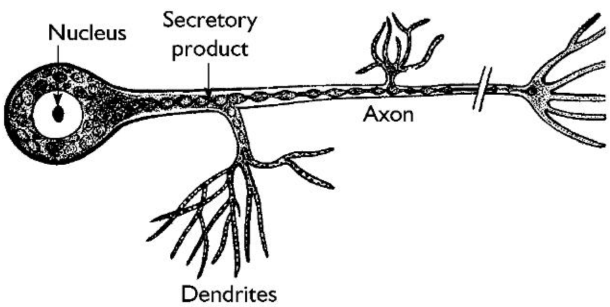
▲ **Fig. 19.1** *Endocrine system of the cockroach; cc – corpora cardiaca, ca – corpora allata, th.g – thoracic gland (M. Gersch, Verlagsgeschleschaft Geest Portig, K. G. Leipzig, 1964)*



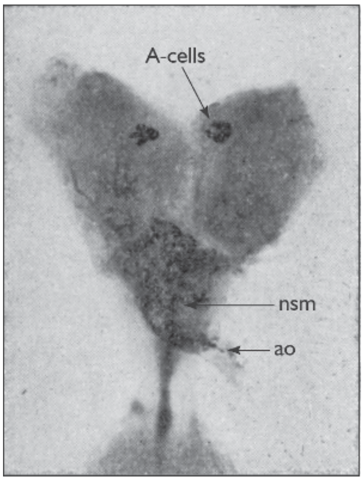
▲ **Fig. 19.2** *Endocrine system of the bug lphita, oes – oesophagus, br – brain, nsc – neurosecretory cells, cc – corpora cardiaca, ca – corpora allata, ao – aorta*

Neurosecretory Cells

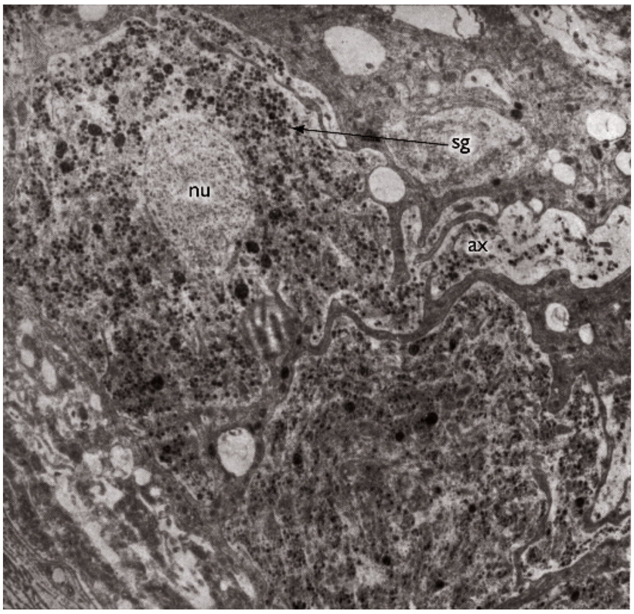
These are secretory neurons, and the secretions exhibit endocrine functions. The neurosecretory cells will be easily observed when appropriate staining methods are employed. They are characteristically neuronal in structure and general properties, but their most significant feature is the secretory nature (Fig. 19.3). They vary in size and tintorial properties (Fig. 19.4). The secretory material arises as electron dense granules in the perikarya in association with the Golgi apparatus (Figs. 19.5 and 19.6) of the cytoplasm. Their axons lead out from the brain posteriorly, most often cross each other and emerge out of the brain



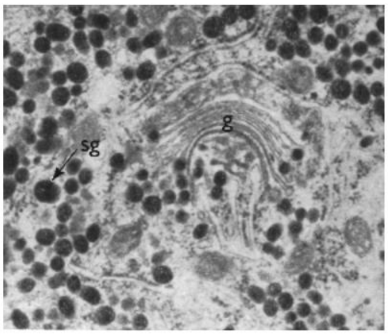
▲ **Fig. 19.3** *Diagram of a secretory neuron (courtesy : K.G. Adiyodi and H.A. Bern)*



▲ **Fig. 19.4** *Whole mount of the brain and posterior regions of Oncopeltus, stained with Victoria blue to show the neurosecretory A-cells of the brain and the neurosecretory material (nsm) at the aortic end. x50 (courtesy: G.C. Unnithan)*

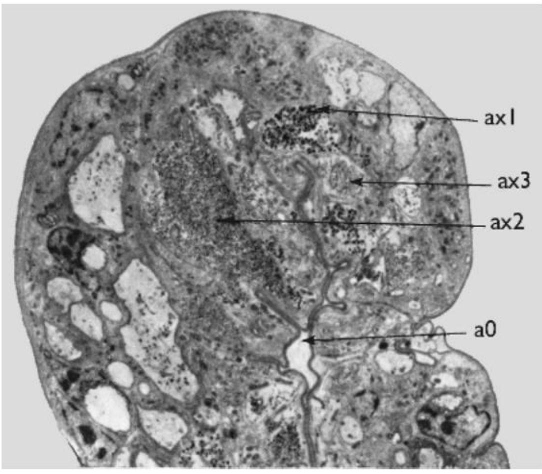


▲ **Fig. 19.5** *Two neurosecretory cells of Oncopeltus. Electron Micrograph: The large dark bodies are lysosomes – ax-axon, nu-nucleus, sg-secretion granule. X5500 (ibid)*



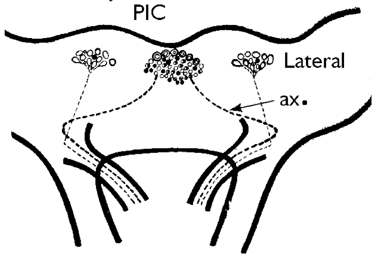
▲ **Fig. 19.6** *A portion of the neurosecretory cell of Oncopeltus at the region of the golgi zone (g). The dark bodies are the secrectory granules (sg). X25,500 (ibid)*

to enter into or lie apposed to the corpora cardiaca. Neurosecretory cells do not innervate any organ. Axons from the cells proceed to blood sinuses or differentiated organs—these latter are recognised as neurohaemal organs. The aorta has been indicated as the neurohaemal site in insects like *lphita* and *Oncopeltus* (Fig. 19.7); while in several examples the corpora cardiaca have been implicated in this release.

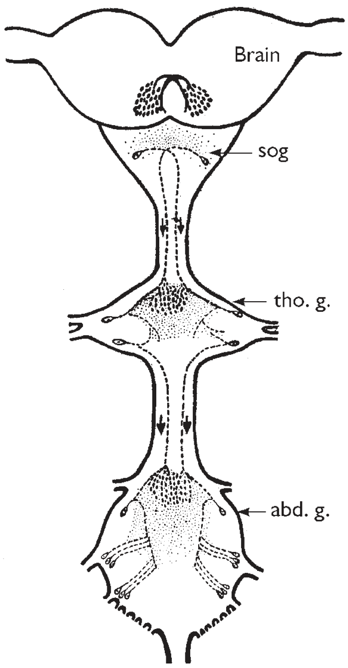


▲ **Fig. 19.7** *Wall of the aorta in section to show the neurohaemal nature of the same. Different types of neurosecretory granules in axons (ax 1 to 3) are seen. X3900 (ibid)*

The neurosecretory cells of the brain occur in two regions (Fig. 19.8), one in the central pars intercerebralis and the other in the lateral lobes. They both give rise to axonic bundles forming the nervi corporis cardiaci to emerge out of the brain. The neurosecretory cells of the ventral nerve cord may be represented in most of the ganglia (Fig. 19.9). Their axons usually release material directly into the blood.



▲ **Fig. 19.8** *Diagram of neurosecretory clusters (PIC, lateral) of the brain and their axonic bundles emerging to the corpora cardiaca (courtesy: H. Schooneveld)*



▲ **Fig. 19.9** *Neurosecretory centres of the brain, suboesophageal (sog), thoracic (tho.g.) and abdominal (abd.g.)ganglionic centres of lphita (courtesy: K.R. Seshan)*

In insects the neurosecretory cells subserve several endocrine functions. One set of secretions is described as the tropic type, which will stimulate another endocrine gland.

The pars intercerebralis of the brain produces the prothoracotropic hormone (brain hormone) which stimulates thoracic glands to produce the moulting hormone or ecdysone. Some biologists have suggested that there is a suppressive function for the product of the lateral neurosecretory cells, which may mediate in the liberation or production of the brain hormone.

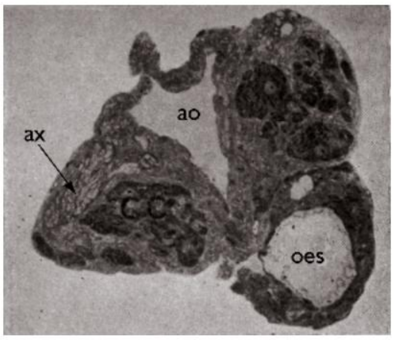
The neurosecretory cells of the suboesophageal ganglion have been shown to exercise an influence on the production of diapausing eggs in the silkworm moth. The brain controls the neurosecretory cells of the suboesophageal ganglion, probably through neural means, or probably by both neural and hormonal means. However, environmental influences also do play a major role in deciding the nature and extent of diapause in insects.

In insects like *Rhodnius*, the neurosecretory cells of the mesothoracic ganglionic mass produce a hormone inducing diuresis. But in locusts, the neurosecretory cells of the brain subserve this function.

In blowflies the brain cells produce a hormone called bursicon facilitating darkening and hardening of the cuticle of the adult. This is a peptide hormone; though produced by the brain, it gets released through the thoraco-abdominal mass of ganglia.

The Corpora Cardiaca

They are paired, small bodies, earlier recognised as ganglionic portions of the stomodeal system. Each corpus cardiacum is traversed by or intimately united with the neurosecretory axons from the brain (Fig. 19.10). The two types of cells comprise the gland, those which get coloured easily in preparations (chromophil) and those not easily tinted (chromophobe). The chromophobe cells are usually posteriorly or laterally displaced, while the chromophil cells lie internally near aorta and often anteriorly. In regular histological sections the axons from the brain are responsible for the choromophil nature of part of the gland. This portion of the corpus cardiacum lies often apposed to or investing the aorta, and comprises a neurohaemal organ. Neurosecretion formed from the pars intercerebralis of the brain, on reaching this region of the corpus cardiacum, is



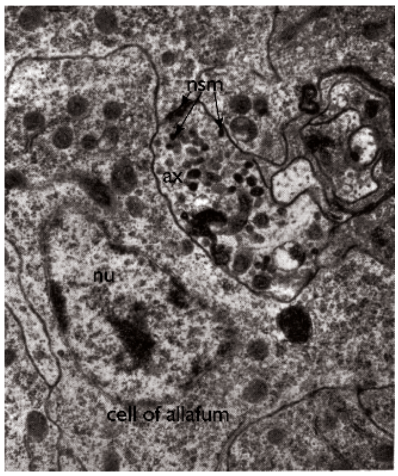
▲ **Fig. 19.10** *Transverse section passing through the region of the corpora cardiaca (cc) of Oncopeltus to show the cells, and the neurosecretory axons (ax) lying close to them; ao – aortic lumenoes – oesophagus, x330 (courtesy: G. C. Unnithan)* stored and periodically released into blood, perhaps after further processing by the secretory activity of the cells of the gland. The chromophobe cells also show inherent secretory droplets.

In the cockroach the corpora cardiaca have been investigated in some detail. When *Periplaneta* feeds, a peptide hormone is released from the corpus cardiacum, (exactly from which region has not been fully understood, probably each part produces one principle), which stimulates peristalsis of the alimentary canal. An acceleration of the contractility of the heart also occurs. These myotropic effects are not due to the direct action of the hormone, but due to a stimulation of pericardial and analogous cells, which in turn elaborates a tryptamine compound inducing the contractions.

Extracts of the corpora cardiaca raises the blood sugar concentration, when injected into *Periplaneta*. This stimulates phosphorylase catalysing the breakdown of glycogen in the adipose tissue and increases the production of the sugar trehalose.

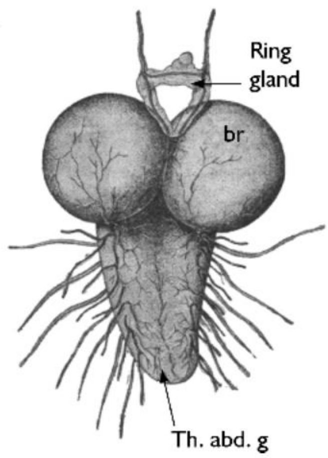
The Corpora Allata

Connected to each corpus cardiacum by axonic bundle is a corpus allatum. Neurosecretory axons also run into the glands (Fig.19.11). The paired condition is lost in some examples like Hemiptera, by coalescence of the two glands into a median corpus allatum. The corpus allatum may be syncytial or with distinct cell boundaries. Actively secreting gland shows the nuclei enlarged and the gland as a whole distended with internuclear spaces filled with transparent secretion. Often a difference in size of the gland is observable in the two sexes, that of the females being large. Thin nerves connect the corpus allatum to adjacent fat bodies and the suboesophageal ganglion. In the larvae of Diptera (Fig. 19.12), a ring-shaped gland (Weismann's ring) comprises a complex organ of endocrine centres—a ventral corpus allatum, a dorsal corpus cardiacum and two lateral tracheal glands which correspond to the thoracic glands.



▲ **Fig. 19.11** *Section passing through the corpus allatum of Oncopeltus showing neurosecretory axon (ax) traversing the gland; nsm – material; nu – nucleus, X19,500 (ibid)*

The hormone that is produced by the corpus allatum is called the juvenile hormone or neotenin (usually abbreviated as JH). Its structure has been identified as methyl 10, 11-epoxy-7 ethyl-3, 11-dimethyl-2, 6-tridecadienoate. Substances which mimic juvenile hormone have been found and phytol, dodecyl methyl ether, farnesal, etc., have been recognised as compounds which can show juvenile hormone activity.



▲ **Fig. 19.12** *The ring gland of larva of Calliphora (M. Gersch, 1964)*

Thoracic Glands

Known by a wide variety of names like ecdysial, ventral, tracheal (lateral ring), and prothoracic glands, the thoracic glands are two laterally placed glands most often seen in the thoracic region of the body. They arise as a mass of ectoderm cells which sink in. Usually the thoracic glands lie limited by a tracheal tube on one side, and appear as two chains of cells. At the period when the gland is actively secretory, the nucleus comes to fill completely each cell.

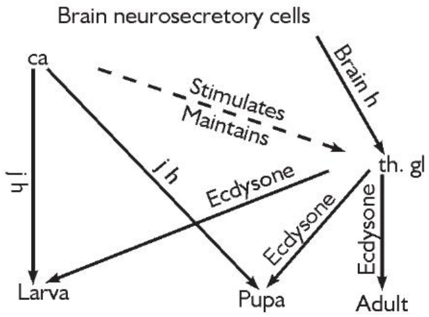
The secretion from the thoracic gland is called ecdysone or the moulting hormone. Two ecdysones are now recognised, α-ecdysone, and occurring in smaller quantities, β-ecdysone. A third ecdysone called ecdysterone has also been recognised. Ecdysone is a steroid. Cholesterol is likely to be the precursor of ecdysone, because it seems to be incorporated into the hormone in radio-labelled studies. Cholesterol cannot be synthesised by insects, though phytophagous forms can convert plant sterols into cholesterol; carnivorous insects derive the cholesterol from their prey.

Endocrine Control of Metamorphosis

Metamorphosis involves phenomena of growth, ecdysis and differentiation. These are manifested in the cuticle which shows the overall change in form between the different instars—nymphs to adults or larvae and pupae to adults. The change in form may be slight as shown by apterygotes, may be more pronounced as in exopterygotes like locusts, cockroaches or bugs, or more complex as in endopterygotes like the caterpillars, pupae and adults of Lepidoptera, or grubs, pupae and adults of beetles.

In apterygotes, the external genitalia differentiate further, but in exopterygotes, wing pads and genitalia gradually differentiate at every moult. In endopterygotes, the larval forms are definitive stages, during which periods adult organs of legs, wings and genitalia differentiate from buds, called imaginal buds, which later undergo a sudden transformation in the pupal stage. The mouthparts, sense organs (antennae, compound eyes) and locomotor structures of the larvae will be quite different from those of the adults, and the replacement of these structures occurs more or less abruptly during the pupal instar. In some endopterygotes all the adult body including epidermis is formed from imaginal buds and cells.

The hormonal control of metamorphosis could be summarised as follows (Fig. 19.13). The secretory brain cells produce a hormone which flows along their axons to the corpora cardiaca from where it gets discharged into the blood. This hormone acts as a trophic one, stimulating the thoracic glands, or their equivalents, to produce ecdysone. At the same time during all but the last moults, the corpora allata secretes the juvenile hormone (neotenin) which decides the development of another larval instar. At the final moult juvenile hormone is not produced, resulting in the emergence of an adult.



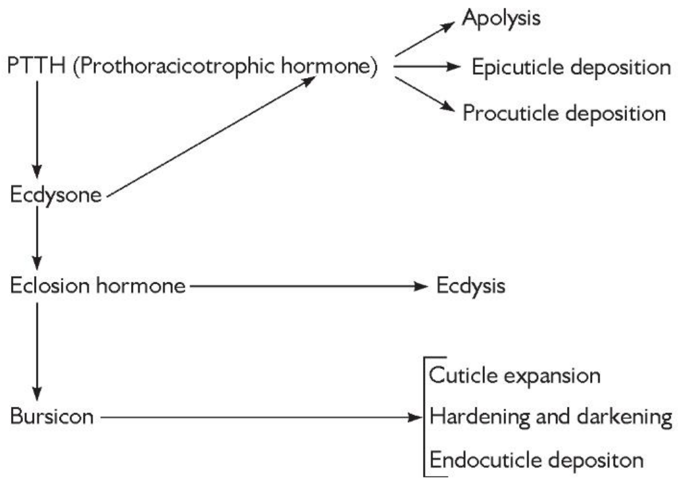
▲ **Fig. 19.13** *Metamorphosis: Schematic diagram of interaction of hormones in post-embryonic development of insects*

Hormonal Control of Insect Development

Bursicon and eclosion hormone are two of the newer components in addition to the juvenile and moulting hormones. Thus the moult cycles of insects are controlled by the prothoracotrophic hormone, ecdysone, eclosion hormone bursicon, each acting after the other in the following sequence.

A well known example which has been fully worked out is that of the blood sucking bug *Rhodnius.* This insect passes through five nymphal instars during its development. The moulting into the adult is that of the fifth nymph and this is termed as the metamorphic moult. During the larval (nymphal) instars there is a gradual increase in development of wing buds, and spotting of the body, and the final moult results in the adult with fully developed wings and genitalia.

In any larval stage, the initial stimulus to moult is the expansion of the abdomen while sucking in a full meal of blood. This stimulates nerve impulses to the brain to produce the thoracotropic hormone, and its release from the corpora cardiaca into the blood. Ecdysone becomes elaborated in the thoracic gland as a result of this trophic influence, and it is ecdysone that initiates the processes that comprise moulting. At the same time the corpora allata secrete the juvenile hormone (JH) which may be described as an 'inhibitory' hormone of metamorphosis. In its presence, the moult evoked by ecdysone is bound to be larval. The corpora allata becomes inactive at the last nymphal moult and the absence of JH at this stage is responsible for the moult into the adult stage.



A number of elaborate experiments have been done which explained the general picture of the endocrine control of metamorphosis. Truman in 1970 suggested an eclosion hormone in silkworm moths to emanate from the brain facilitating adult emergence and activating abdominal ganglionic centres which control the breakdown of muscles and initiate motor behaviour.

Once the adult stage has been attained, the insect does not moult again. It has been found that this could be attributed to the lack of ecdysone production because the thoracic glands degenerate shortly after the insect moults into the adult instar.

Mode of Action of Hormones

Experiments have shown that ecdysone will initiate moult and differentiation to the adult form and that the JH modifies this towards a larval type when it is present. Analysis of this has led to the finding that in epidermal cells, features associated with the restoration of protein-synthesis occur on exposure to ecdysone, like enlargement of nucleoli, appearance of RNA in cytoplasm and increase in number and size of mitochondria. It is likely that ecdysone affects the DNA of the nucleus to induce synthesis of specific proteins. This has been shown in the production of the activator enzyme during synthesis of N-acetyl dopamine quinone in the puparium of *Calliphora*. The giant (polytene) banded chromosomes of larval Diptera show what are called puffs, which are the inflated regions representing major sites of RNA synthesis and noted to be *m*-RNA material. They are tissue-specific and help in elaboration of specific proteins of the tissue; in addition there are puffs which are related to the developmental stages. It has been shown that the latter could be induced by appropriate administration of ecdysone. These are all indicative of the fact that ecdysone acts at the chromosomal level.

Functionally JH has been described to be a modifier or inhibitor; it could be interpreted as a programmer of gene activities. However, this aspect has not received critical study.

Hormones and Ecdysial Behaviour

Shedding of the old cuticle is the terminal event of the moult cycle. The old cuticle loosens as a result of sequence of preecdysial movements. Ecdysial behaviour is released by the eclosion hormone, discovered first in the giant silk moth. The eclosion hormone is produced by the neurosecretory cells of the brain of the preecdysial adult and stored in the corpus cardiacum. In the last instar larva, it is also synthesized and stored in the ganglia of the abdomen and thorax and then released from these centres before pupal ecdysis. Ecdysone hormone acts directly on the ventral nerve chord to release the ecdysial behaviour for the pupal, adult and larval moult.

Just after eclosion, the hormone induces degeneration of the special muscles needed for moulting and increases plasticity of cuticle to allow wing expansion. At pupal ecdysis the eclosion hormone stimulates the dermal glands to produce the cement layer that helps to waterproof the cuticle. Though not discarded in all orders it is confined mostly to Lepidoptera.

The ventral nerve chord is the target for the eclosion hormone. Tanning and cuticle expansion are controlled by bursicon produced by the neurosecretory cells of the brain. It is released by the neurohaemal organs i.e., Corpora allata and Corpora cardiaca, associated with the thoracic and abdominal ganglia. Bursicon affects many post-ecdysial processes:

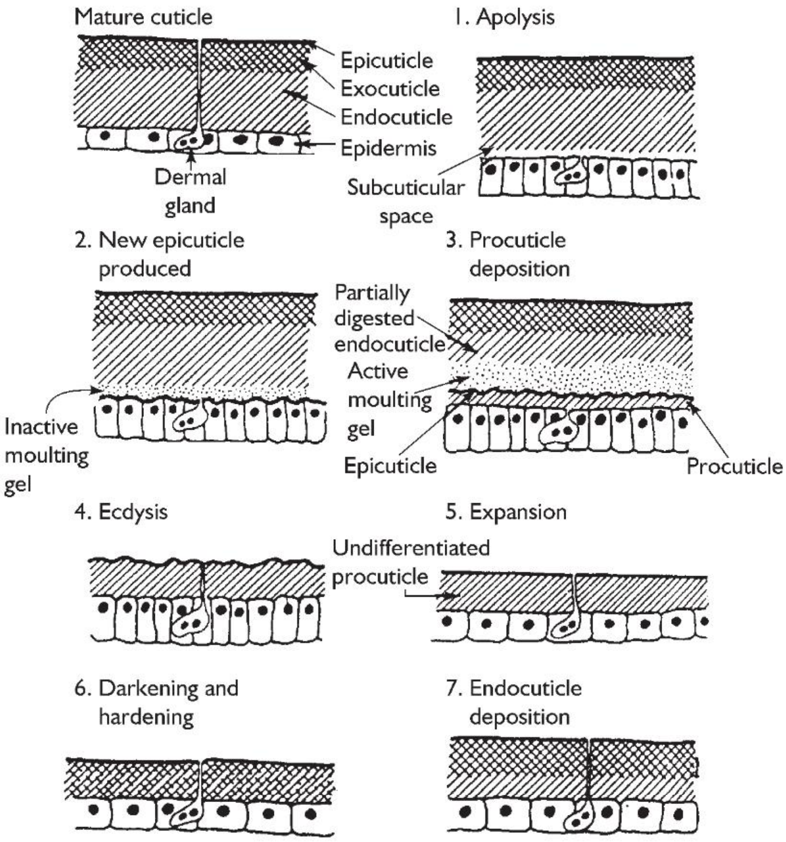
- It promotes synthesis of precursors of tanning quinones.
- It plasticises cuticle so that expansion takes place.
- It leads to thickening of the endocuticle.

Moulting is a complex process with seven major steps—apolysis, epicuticle formation, new procuticle deposition, ecdysis, procuticle expansion, hardening and darkening, and innermost endocuticle deposition (Fig. 19.14). *Apolysis* is retraction of epidermal cells from the inner surface of the old endocuticle. A subcuticular space is formed between the cells and cuticle. Into this space moulting fluid is secreted and beneath the moulting gel a new cuticle is laid down. During epicuticle formation the first layer to be laid down is the *cuticulin,* which is extensively wrinkled and folded. Procuticle deposition occurs by the formation of chitin microfibrils in the subcuticular space below the inner epicuticle. A new procuticle is formed, the inner endocuticle of the old cuticle becoming digested by the moulting fluid, which contains digestive enzymes.

Ecdysis occurs when the old cuticle splits along a mid dorsal ecdysial suture. The cast skin consists of epicuticle, exocuticle and includes lipids, proteins and chitins.

Expansion of soft, whitish cuticle takes place as the insect swallows air to inflate and smoothen out the wrinkles in cuticulin and at this stage much of the cuticle is stretched out to allow increase of surface area.

Hardening and darkening stabilize the new procuticle. Quinones formed by oxidation of diphenols, cross link cuticular proteins form the exocuticle. Endocuticle deposition includes laying down of both chitin and protein which continues for sometime after ecdysis.



▲ **Fig. 19.14** *Moulting sequence*

Endocrine Influences on Reproduction

Corpora allata of the adult female secrete a hormone which influences development of eggs by controlling deposition of yolk. This is often designated as a gonadotrophic function. After the lull in activity of the glands during the last larval (nymphal) instar, they resume their endocrine function in both the sexes of the adult insect, but only in the female the gonadotrophic influences have been well studied. In the males the accessory glands which elaborate substances to form the spermatophores have been seen to be controlled by the hormone of the corpus allatum.

The development of the egg is completed only if the corpora allata continue their endocrine activity. In many groups of insects, except in stick insects and Lepidoptera, egg growth occurs only when the corpora allata are present and active. In Lepidoptera and phasmids, egg development continues in the absence of these glands.

Whether the juvenilising hormone of the larva and the gonadotrophic hormone of the adult female are the same or are different, has been debated, but it is generally agreed that the two are the same. It is also to be mentioned that there is no sex or species specificity for the corpus allatum hormone.

Analysis of the haemolymph has been made electrophoretically, and specific additional protein groups have been obtained in females. After labelling them with flourescein isocyanate, which flouresces in ultraviolet light, they were seen to get into oocytes when injected into a female, indicating that their specific protein groups get incorporated during egg growth. The blood proteins have been found to be synthesised in the fat bodies. In *Rhodnius*, the function of corpus allatum thus is subserving a metabolic function:

Corpus allatum→Fat body→Blood protein→Ovary

In some insects like cockroaches and blowflies, the neurosecretory cells of the brain influence the oocyte growth in addition to the corpus allatum. However, a detailed study of many insects alone will warrant any generalisations.

The female accessory glands grow and become active when the eggs are growing or nearly fully formed. These may perhaps be influenced by the hormone from the corpus allatum. The organs respond to a lower concentration of the hormone than do the eggs.

Starvation is one of the extrinsic factors that affects reproduction seriously. There is disturbance in the activity of the corpus allatum following starvation.

Cyclic development of eggs occurs in insects which ovulate at intervals. Concomitant with this activity, seen in cockroaches, bugs, etc., is a cyclical secretory activity of the neurosecretory cells of the brain and the corpora allata. Active feeding and mating have stimulatory effects on this.

Oviposition has been also attributed to some as yet undefined hormonal influence, perhaps from the neurosecretory cells of the brain. The neurosecretory hormones released during oviposition probably have a role in inducing oviductal and uterine motility. Pheromone production is under the control of the corpus allatum in several insects.

Sex Hormones

Several insects exhibit sexual dimorphism, males often seen with elaborate antennae, outgrowths, and wings, and females lacking such marked structures. However, a sex hormonal mechanism has not been recorded, and in fact the presence of a sex hormone has been vigorously denied by several authors.

Studies by Naisse have questioned this view by adducing good evidence for the presence of sex hormone in insects. She studied the glow worm *Lampyris* whose female is wingless, large and with reduced eyes and the male winged and with large eyes. Sex differentiation appears at the third moult. In male, at the apex of differentiating testes is a special tissue, which becomes an androgenic gland. This gland is active from third moult to the pupal instar, after which it degenerates. In the female such a tissue is absent. If the tissue with the testes from three, four, or five instars of the male are implanted into females of the corresponding stages, the females become masculinised. Ovaries get modified into testes, genital ducts appear as in males and somatic male characters develop. These 'neomales' can fertilise a female. But when implanted in pupal stages, the females remain unaffected. Late pupal or adult male material does not possess the male inducing influences. Ovariectomised larval female receiving similar implants, though masculinised, remain sterile. Ovary does not possess any feminising effect at anytime. Certain neurosecretory cells of the brain become active during the active period of the androgenic tissue, removal of such cells in early larval males will induce the insects to grow into females in most of the experimental insects.

Pheromones

These are substances secreted by insects when eliciting a specific reaction from another member of the same species. 'Queen substance' of the honeybee, the sex attractants of various groups of insects, the alarm substances in ants, the maturation pheromones in termites, etc. are examples. They function as chemical messengers between individuals of the same species.

Of importance in insectan reproduction are the sex attractants, which help to attract the opposite sex. Sex attractants are produced in silk moths, gypsy moths, cockroaches etc. The female silk moth produces a substance—bombykol, the female gypsy moth produces gyptol. The males will respond to very small concentrations of these odorous substances, 10-12 μg of bombykol or gyptol will be sufficient. The female cockroach–*Byrostria* produces an anal and a tergal secretion, and the corpus allatum regulates the production of these pheromones. When the activity of the allatum is minimal, the female *Periplaneta* also is non-responsive. In Lepidopterans like *Bombyx*, however, the adult endocrine system has no control over pheromone elaboration. The honeybee sex attractant is a dual-action pheromone—in addition to its function as a sex attractant, it also affects the workers (females)—in influencing their behaviour and development. This pheromone is identified as 9-oxo-*trans*-2 decenoic acid. In worker bees, the growth of the ovary is normally inhibited. The removal of the queen, (which is the sole reproductive individual of a bee colony) will induce construction of large cells and rearing of larvae to queens by supplying special food. At the same time worker bees will also be growing their own ovaries. The pheromone of the queen bee is elaborated as a secretion of its mandibular glands which is imbibed by workers during the grooming activity. How the corresponding inhibiting effect is brought about is not known.

In some butterflies the male produces the pheromone, which is the sex attractant and dusts the female with it or the female perceives it by rubbing her antennae against the scales which produce it. Usually the transfer of scent is effected during flight of the two sexes and consummates in copulation.

In the termite *Kalotermes*, the royal pair (male and female) inhibits the development of gonads in the workers of its own sex. Also each stimulates the pheromone production of the other. Other pheromones decide the other castes or their extermination whenever necessary. It is believed that the influence is brought about through the endocrine system of the recipient, i.e. it is a pheromone-hormone interaction.

Ant trail substances are pheromones and the foraging ants follow this trail to and fro, from the food source to the nest. In *Pogonomyrmex,* the pheromone in low concentration is an attractant but at higher strength it behaves like an alarm substance on the members of the colony. This elicits aggressive behaviour and abdomen lowering, sometimes amounting to 'digging' behaviour.

In *Schistocerca,* the mature males elaborate a pheromone, accelerating maturation of other males and females. Removal of the corpora allata affects the production of this pheromone. The insect matures due to endocrine influences and the pheromone is thought to stimulate the endocrine activity.

◆ Chapter 20

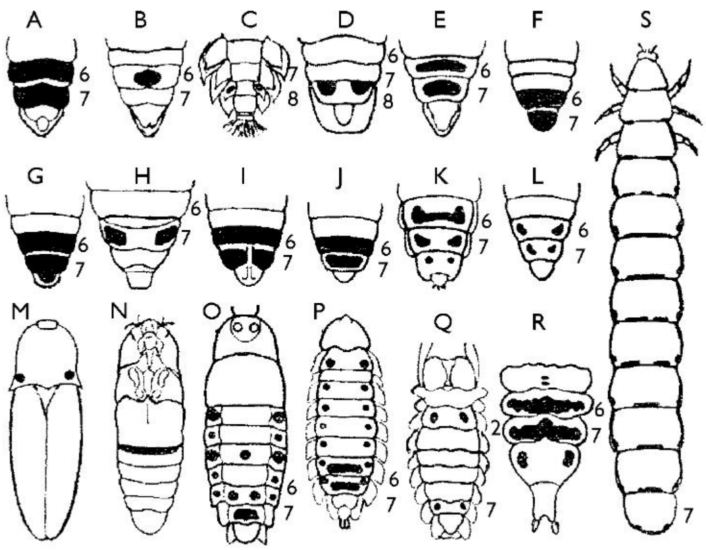
Bioluminescence

The fireflies and the glow-worms belonging to the family Lampyridae (Coleoptera) and the fungus gnat larvae (Mycetophilidae : Diptera) and some cantharoid and elaterid beetles have evolved with light producing organisms, with a large number of species in each group. The evolution of light organs among fireflies and glow-worms is connected with reproduction. One of the very common examples relates to the female larviform lampyrid *Lamprophorus tenebrosus* and its winged male, where light is used to attract the sexes. The chemical processes connected with light production relates to a substance *luciferin*, oxidized in the presence of an enzyme *luciferase*. Another compound in the firefly adenosine triphosphate is also involved. The luciferins are different in different species and today both the luciferin and luciferase in the firefly are available in the crystalline form. The empirical formula of luciferin found in the firefly is $C_{12}H_{12}N_2S_2O_3$. Interestingly enough, a beetle larva in South America has been called the 'rail-road worm' because it has lights of two colours, a row of greenish yellow luminous spots along its sides and a red light on its head. When crawling along the ground it resembles a train and hence the name 'rail-road worm'.

The light producing or photogenic organs are located beneath areas of transparent cuticle and they vary greatly in size, shape and position in relation to the sex and developmental stages of different species. There are 11 or 12 segmentally arranged pairs of photogenic organs as in *Phryxothrix* and *Phengodes*, or in females of many species such as *Lampyris* these may be found principally on the 6^{th} and 7^{th} abdominal sterna (Fig. 20.1). They may also occur on the pronotum and anterior abdominal sterna as in *Pyrophorus*. The photogenic organs are present in both sexes as in the Elateridae and *Luciola*, and in the females which are apterous and larviform. The light emitted may be of continuous glow or an intermittent one or pulsating glow of variable intensity or periodic flashes, and this depends on the species concerned. Light emittance are said to be influenced by environmental factors.

About one hundred species of luminous beetles belonging to the genus *Pyrophorus* from Fiji Islands are known. Elaterid beetle lights are known to be brighter than lampyrids. All individuals of *Pyrophorus* have two bright anal luminous spots along sides of prothorax and a large one on the ventral side of the first abdominal segment. Some lampyrids are luminous throughout life. In *Photinus* and *Photuris* the adult light organ is completely reformed during pupal period and appears in a different position in the abdomen. The light organs do not flash as they lack tracheal end cells, as is evident in *Lampyris*.

Sexual dimorphism among lampyrids is well evident. If both sexes are winged, the male has larger light organs and greater activity. If the male is winged and female apterous



▲ **Fig. 20.1** *Location of Light Organs in Diverse Families of Coleoptera Photogenic organs indicated in solid black. Numbers refer to abdominal segments. Ventral views, unless otherwise indicated. Sizes are variable and not shown to scale. A. Photinus scintillans, Male; B.P. scintillans, female; C. Photuris pennsylvanica, larva; D. Diphotus montanus, male; E. Photuris pennsylvanica, female; F. Luciola chinensis, male; G.L. cruciata, male; H.L. lusitanica, female; I. Luciola sp., male; J.L. lateralis, male; K. Pyrocoelia rufa, female; L. Lecontea lucifera, female; M. Pyrophorus noctilucus, dorsal; N.P. noctilucus, ventral; O. Lamprorhiza (Lampyris) splendidula, female; P. Phausis mulsanti, female; Q.P. delarouzeei, nymph, dorsal; R. Lampyris noctiluca, female; S. Phengodes sp. dorsal (E. Newton Harvey, The Quarterly Review of Biology, 31:281, 1956).*

as in *Lamprophorus tenebrosus,* the female has more conspicuous light organs. Occasionally both sexes may be apterous and luminous. The ability to luminescence can be considered an adaptation for living in the dark, as in lampyrids, which is a wonderful adaptation for bringing the sexes together. The light produced by the cucujid beetles is so powerful, that primitive tribes use a couple of them in glass holders for lighting their huts. *Luciola gorhami* is an equally common Indian glow-worm.

Among fungus gnat larvae belonging to the family Mycetophilidae several species exhibit luminosity. The larvae and pupae of *Ceroplatus sessiodes* exhibit luminosity. In *Arachnocampa luminosa* the larvae spin webs from which hang glutinous threads emitting light in dark places. The light emission from fungus gnat larvae does not involve the development of complicated light organs as in fireflies. On the other hand it is merely an aggregation of luminous cells.

◆ Chapter 21

Communication in Insects

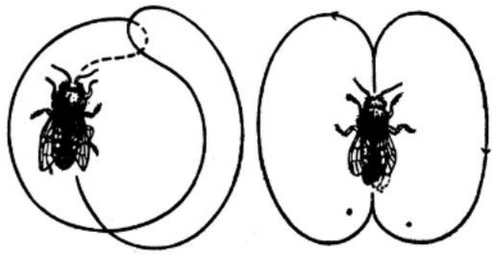
A sensory signal which elicits a behavioural change in an animal is a form of communication. In insects communication need not come from another insect but could emanate from a plant. The coded forms of signals constitute the language and may be auditory, visual, tactile, or chemical. Auditory communications have already been outlined in the chapter on sound production.

Behaviour patterns relating to feeding, reproduction, movement, etc. involve a variety of these signals, and some aspects of these have been already covered in biology of reproduction.

Visual communication employs various signals which will be perceived by the eyes of the insects. The colouration of wings and other parts of the body, and the rate and speed of movement of such parts afford signals of value. In the butterfly *Hipparchia* it is the movement of the wings and not the pattern that is perceived by the males to recognise the mate. This has to be taken into account because some insects show a batesian mimicry and escape attention except when flying. As a means of communication to other species, mullerian mimicry is of significance in confusing predators.

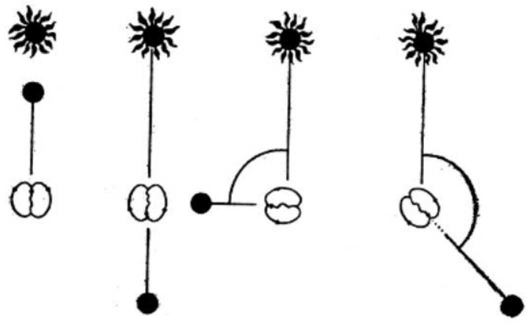
Flashing signals of fireflies are species specific, characterised by the rate and duration of flash. How the female recognises the signal of the species is not certain, but probably it is a genetically-determined recognition. Threat displays are signalled by moths and mantids; the eye spots of moths, and streaks of colour as a warning pattern are examples. A real-false signal used with advantage is the flashing exhibited by *Photuris* to lure the males by imitating the flashes of the female of the victimised firefly.

Communication about sources of nectar is by a system of dances in the honeybee (Fig. 21.1). The workers scouting in search of food, on finding one in a neighbouring area perform what has been described as a round dance. This is to pass on information to the rest of the scouts in the colony. The forager which has discovered the food and has drunk from the source, comes to the comb and lets a drop of honey seep out on to her proboscis. A few bees take this fluid up with beating of the antennae. Then the scout that has returned to the comb starts a round dance, swiftly running in a circle of small diameter, suddenly reverses her direction and turns again to the original course, this being repeated twice or sometimes up to 20 times. When several circles are run, the insect moves over several comb cells. The food sample is redistributed on termination of the dance. Dance is resumed twice or thrice again and abruptly ends. The bee then takes off, followed by the other workers. This communication to the comb mates is a usual method of signalling and the returning bees also dance enlisting more foragers to go out. On the abdomen of the bee, situated between the sixth and the seventh tergites, is a scent organ which is everted and the wing movements fan the volatile particles as a cue to colony mates; this happens in workers which are replete with food.



▲ **Fig. 21.1** *Dance communication in the honeybee. On the left is the round dance and wagging dance is on the right (N.M. Jessop, 'Biosphere', Prentice-Hall Inc., Englewood Cliffs;)*

If, however, the source of nectar is far away from the nest, about 100 metres or more, a new type of dance called tail-wagging dance is employed. Here the bee runs straight ahead for a short distance, and moves in a semicircle to the starting point, runs through the axis and describes a semicircle in the opposite direction; these movements are repeated as regular alternate runs. Rapid side-wise wagging of the body, which is maximum at the abdominal tip, is also exhibited. The to-and-fro movement is repeated about 15 times a second. At the same time a buzzing sound is produced by the dancer. Depending on the distance to the source of the nectar, the tail wagging dance extends over a few to a larger number of combs, the latter when the distance is more. Tail wagging dance is an elaborate modification of the round dance. The tempo of the wagging dance indicates the distance to be covered—when the tempo is slow the distance is more. This is a relationship valid up to a distance of over 10 km. External factors like temperature, headwind, slopes, etc. affect the tempo and so though the distance is spelt out it is not absolute. Besides informing the foragers about the distance, they are told about the direction to the source. When tail wagging is done on a horizontal part of the rest, the wagging run points to the goal. The bee flies in the direction (azimuth) of the sun, which is a simple phototaxis (Fig. 21.2)



▲ **Fig. 21.2** *Relation of dance to the position of the sun (above) and the food source (black circle) (ibid)*

In a dark protected hive the run is vertical and sense organs for perceiving gravity come into play. When there is a cross wind a slanting angle is selected heading obliquely across the wind. Sometimes misdirections are given due to interference between sun's light and polarised light. This is usually avoided by the insect's dependence on its sense of gravity and indicative runs guided by that cue. Foragers feeding or descending in an area attract the scouts by employing the scent from their abdominal glands.

The nest is kept at a fairly constant temperature (34–35° C) independent of the temperature outside. There is a system of cooling to maintain this temperature at first by fanning with wings and when the temperature rises above 35°C by evaporation of water carried to the hive and distributed in droplets. The droplet is exuded at the mouth and spread with the proboscis into a film. After evaporation a new film is formed again. Only experienced foragers go out to fetch water and younger workers distribute it in the hive. A special method of communication is employed to fetch water when it is needed and stay back at other times. When the hive starts to get very warm, the young workers regurgitate the diluted honey from their gut (60 per cent of which is water) and form films to evaporate water. This is the signal for experienced foragers to go out in search of water. Homecoming foragers are relieved of their water burden assiduously. Several bees will rush up to the water carrier and suck the extended droplet of water. When overheating subsides, the tempo wanes and in a short time the water carrier returning home is ignored. This is the signal to stop water collection.

Some members will be bringing in resinous secretions, and they also perform a dance to indicate that they have discovered a source of propolis.

Other dances are also performed by bees in communicating with the members of the hive. One is the spasmodic dance, running agitatedly about the comb in various directions to indicate food source in the vicinity of the hive. The sickle dance which is a halfway dance between the round and wagging types, is not yet fully understood. The swarm is induced to decamp to a new site by a buzzing run–zig-zag runs accompanied by a hissing sound producted by vibrating wings. Neighbours are informed to groom a bee by its shaking dance performed standing on hind legs, swaying the body, even as a midleg clears the body surface. This will induce another bee to come up to it and clip and clean the sides of the body by her mandibles very much like a 'barber' bee. The abdomen itself is moved up and down rapidly by a bee in a jerking dance motion after inviting the attention of a bee by striking with her antennae and sometimes climbing on to her. This may be shown also by the queen about to perform the nuptial flight. Though mentioned as a dance of contentment, its occurrence in a starving colony is inexplicable.

Various races of the honeybee have the same language known as dialects. The simplest variety of the language is seen in primitive bees like *Trigona* when the mates recognise agitated runs as indication of excitement of discovery and the workers fly out to explore and find out the source for themselves. The smell is the major cue offered here and a collision with the agitated insect gives the hint about the quality of food.

Tactile Communication

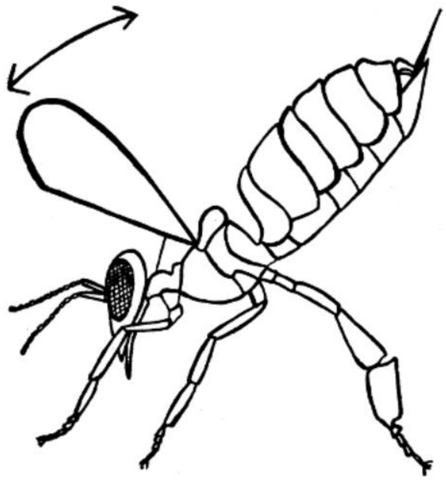
In the honeybees there is also tactile communication involved. The contact with parts of the body, and antennal touches are important sources that come into play in the life of the bees.

Chemical Communication

Communication by transmission of chemical substances between insects is an important method, also very well developed in social insects. In insects, sex attractants, alarm substances, trail substances and recognition odours occur as chemical communication systems.

Sex attractants stimulate specialised receptors. Where the males get attracted to the females, the chemical signals are perceived by antennae; sexual chemoreception occurs through the agency of sensillae basiconica and coeloconica. Male attractants are also called aphrodisiacs. Several insects are known to produce attractants to entice males. Likewise, females are attracted by male scents as in *Danaus.* Sometimes virgins produce an attractant which will entice both sexes to her, as in *Dendroctonus.* The sex attractants are produced from a variety of organs like abdominal glands, specialised tufts of hair, mandibular glands, scales, etc.

One set of pheromones elicit alarm reactions. These are the alarm pheromones, found in honeybees and ants (Fig. 21.3). Reactions triggered range from rapid spurts of running or evasion and assumption of threat posture to complete evacuation from a site of disturbance will be produced. Undecane, tridecane, 2-tridecanone, citronellal, etc. are the potent alarm substances of ants; citral, isoamylacetate, and 2-nonanone are their counterparts in the bees. In the ant *Atta*, the same pheromone in smaller quantities will be a signal for aggregation, but in larger quantities will signal alarm while in *Pogonomyrmex* smaller quantity will function as a sex attractant.



▲ **Fig. 21.3** *Alarm position assumed by a bee. Alarm substance from tip of abdomen is wafted by wing which moves in the direction of the arrow (modified from Maschiwitz, U.,Z. Vergl. Physiol.,* **47:** *596–655, 1964)*

Trail laying in ants is by means of a chemical which marks the ground as the foragers move to a site of food or back to nest. These trails are followed by other members of the colony. The trails are often polarised indicating the direction in which it has been laid as in the bee *Trigona* and the ant *Lasium.* Trails laid often last only for a short time, but they are reinforced occasionally by the ant workers moving along the path. Trails laid by different species criss-cross in an area but the workers do not get confused as the trails are species specific. The trail is laid by Dufour's gland and are laid only by workers who have succeeded in finding a site with food. Some of the other organs concerned with production of trail substances in different species are:

Organs	*Species*
Hindgut	*Eciton, Lasium*
Hindgut and stomach	*Neivamyrmex*
Poison gland	*Tetramorium*
Metathoracic leg	*Crematogaster*
Pavan's gland	*Iridomyrmex*

Hive or nest mates have characteristic odours aiding in perception by the members of the colony; this is recognition scent. The male bark beetles, while burrowing into wood, release the pheromone into the lumen of the hindgut where it becomes incorporated into the faecal pellets; pheromones released by the pellets help in orienting flying populations to the vicinity.

The quantity of substance eliciting response is usually employed with the utmost economy. In *Bombyx*, the male responds to a signal having concentration as low as 200 mol/cm^3. With a gland capacity of 10^4 molecules in the reservoir, the full discharge can cover a volume of air elliptical in shape and elongated to several kilometers in the direction of prevailing conditions of wind.

The substances employed in chemical communication do other functions as well, like curbing the formation of queen cells in honeybee or inhibiting development of sex organs in termite pseudergates.

In ichneumonids (*Endasys, Pleolophus*), females have been found to respond to their own trail odour and recognise pre-searched areas and intra-specific trails for a more effective dispersion of the parasitoids.

Defence by Chemical Means

Two categories of defensive substances are elaborated by insects which function as signals to other insects or animals that they are better left unharmed. One is glandular secretion and the other is non-glandular. Eversible glands or osmetaria of caterpillars of *Papilio* evert and smear offending insect or animal with the secretion which contains isobutyric acid. In the beetle *Chrysomela* a secretion oozes out containing salicylaldehyde from the back of the larva. The beetle *Galerita* sprays a secretion containing formic acid on contact stimulation by an offender. Predators elicit ejecting and spraying of saliva up to several feet in the bug *Platymeris.* The bombardier beetle *Branchinus* generates benzoquinones, by mixing hydroquinones and hydrogen peroxide from one gland and enzymes from the other, the ejection being at a temperature of 100° C. A fluid discharged from the back of *Poekilocerus* by forcing air from tracheal system contains histamine and cardinolides.

Blood and other systemic fluids form nonglandular chemical signals in defence. Three chemical signals may include reflex bleeding as in meloids, blood oozing out from joints in legs of *Epilachna*, regurgitation of food occurs in *Pogonomyrmex* and in various grasshoppers, and dry faeces ejection that occurs in the chrysomelid *Cassida.* Regurgitation and defaecation are chemical signalling on the part of these insects to ants. Butterflies which show warning colouration are avoided by birds, since they will vomit if they feed on it. Cantharidine of meloids produces gastroenteritis in vertebrates.

Group defence in social insects is mediated through alarm pheromones. Such pheromones alert the colony to a state of emergency causing workers or soldiers to be enlisted for defence. Definitive secretions may also serve as secondary-alarm pheromones. This is borne out in cases which live in aggregations like passalids, *Dysdercus*, etc. There is an interesting example in *Anisomorpha* where the small male stick insect with smaller amount of defensive secretion profits from pooling the resources with the female which is large and with copious secretion. The male sits astride the female, a posture which originates in nymphal stages, for defensive exploitation. Defensive secretions afford another parallel example of chemical communication system.

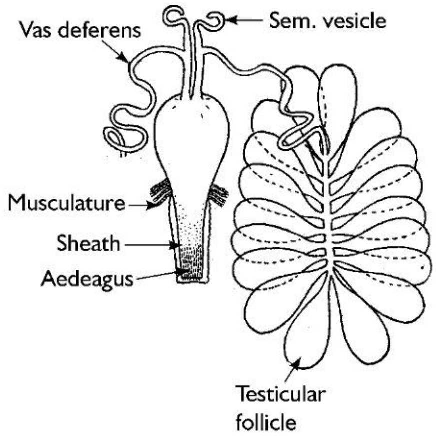
◆ Chapter 22

Reproductive System

Reproduction in insects is an essential physiological process from the view point of propagation of the species and, as mentioned earlier, naturally results in the high biotic potential of insects, making them a successful group of animals. Reproduction always does not imply the bi-sexual methods, but other processes like parthenogenesis, polyembryony, etc. may also be involved. However, sexual reproduction is by far the most common. Sexual differentiation on the basis of the external appearance, though possible in many insects, is not always the rule. Normally the males are smaller than the females; in female cockroach the abdomen is short and broad, and in the males narrow and elongated; in many flies the compound eyes of the males touch each other while they are wide apart in the females; and in Strepsiptera the adult female is wingless, the males are winged. The organs of reproduction–the testes in the males and the ovaries in the females-–are abdominal in their position and the ducts leading from them open externally near the posterior end of the abdomen. The male genital ducts are called vasa deferentia, and the female ducts, the oviducts. These are mesodermal in origin but the median ducts formed by their union, the ejaculatory ducts of the males and the vagina of the females, have a lining of cuticle.

Male Reproductive Organs

These consist of a pair of testes (Fig. 22.1) leading to lateral ducts, the vasa deferentia. Each testis consists of groups of sperm tubules or follicles called the testicular follicles containing the sperm or the germ cells in various stages of development. Each sperm tube leads into a vas efferens, a thin tube and the vasa efferentia in turn open into the vas deferens. In view of the development of the germ cells within the sperm tube, the upper part of the latter contains the primary spermatogonia and is called the germarium. This is followed by the zone of growth where the spermatogonia undergo multiplication. In the next zone the spermatocytes become transformed into spermatids and then develop into spermatozoa and is termed as zone of transformation. The vasa deferentia leading from the testes are of varied lengths in different insects, and in many, each deferens becomes enlarged along its course to form the vesiculae seminalis in which the spermatozoa accumulate. The two vasa deferentia unite to form the median ejaculatory duct or ductus ejaculatorius, the terminal end of which is enclosed in the intromittent organ, the penis or aedeagus. One to three pairs of accessory glands are usually associated with the genital ducts. These may be saccular, or tubular, or densely branched tubules, as in the mushroom-shaped gland of the cockroach. The accessory gland of the males secretes the seminal fluid. Opening into the seminal pouch and lying below the ventral nerve chord, in cockroaches is a club-shaped conglobate gland.



▲ **Fig. 22.1** *Male reproductive system of Perlesta (courtesy: K.W. Stewart year)*

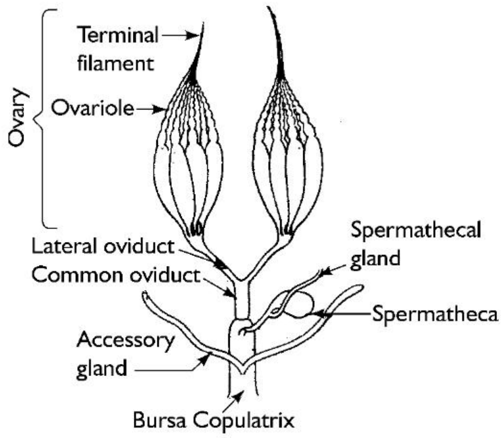
Female Reproductive Organs

The female reproductive organs (Fig. 22.2) consist of paired ovaries lying in the body cavities on either side of the alimentary canal, each ovary being composed of a variable number of ovarioles or egg tubes opening at their proximal ends into the oviducts. At their distal ends the ovarioles converge to form thin filaments uniting to form a suspensory ligament attached to the body wall or to a fat body. The number of ovarioles may be variable and may range from a single ovariole in some flies to thousands in the termites. Each ovariole contains eggs in various stages of development and disposed one behind the other in a single chain.

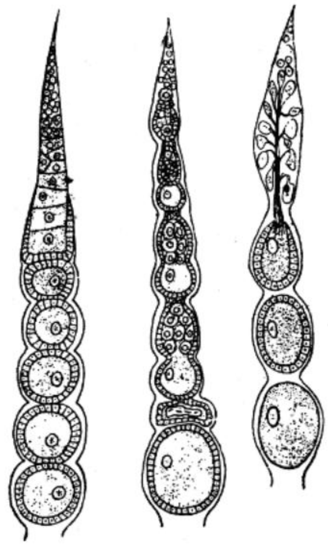
Basically the ovarioles (Fig. 22.3) are of two kinds according to the nature of the nutritive cells they contain:

1. Panoistic ovarioles are the primitive ovarioles, which does not contain any special nutritive cell.
2. Meroistic ovarioles are the ovarioles where the eggs alternate with the nutritive cells, or nurse cells, or trophocytes.

The meroistic type provides further modifications into: (a) the polytrophic ovarioles where each oocyte has several trophocytes enclosed within its follicles and (b) the acrotrophic or telotrophic ovarioles where the nutritive cells are confined to the apex of the ovarioles and are connected to the developing eggs by long nutritive cords.



▲ **Fig. 22.2** *Female reproductive system—diagrammatic (Snodgrass, 1935)*



▲ **Fig. 22.3** *Ovariole types: Panoistic (left), polytrophic (middle), and telotrophic (right)*

The panoistic ovarioles are primitive and are characteristic of Ephemeroptera and Orthoptera, the polytrophic ovarioles occur in Dermaptera, Lepidoptera and Hymenoptera, and the acrotrophic ovarioles in some Hemiptera and Coleoptera. Each ovariole is principally divided into an anterior germarium with the germ cells in an active state of division and a posterior vitellarium or the zone of growth where the eggs grow. As a result of the growth of the oocytes the vitellarium becomes divided into egg chambers.

The pedicels or the stalks of the ovarioles open into the lateral oviducts which are paired canals leading from the ovaries and uniting to form the common oviduct opening ventrally on the seventh, eighth or ninth abdominal segments. For purposes of storage of spermatozoa received from the males during copulation there is a sac opening on the dorsal wall of the vagina called the spermatheca or receptaculum seminis. Some insects in addition have a pouch for the reception of the seminal fluid even before they pass into the spermatheca called the bursa copulatrix. Lepidoptera quite unusually possess two sexual openings, an orifice behind the sternum of the eighth abdominal segment leading into the bursa copulatrix and the vaginal organs on the ninth segment. Accessory glands present as fine threads and opening into the oviduct in many Orthoptera serve to secrete the egg case or capsule. In many other insects accessory glands secret a substance for cementing the eggs together or fastening them on to other objects.

The reproductive system undergoes a variety of modifications by divisions of the reproductive glands into multiple lobes, additions or modifications of genital ducts. In Plecoptera, Trichoptera, Lepidoptera and Hymenoptera such modifications are frequent; one example is shown in *Perlesta.*

Other methods of reproduction have been frequently reported in insects and include parthenogenesis, viviparity, polyembryony, hermaphroditism and paedogenesis or neoteny.

Determination of Sex

Important roles are played by the chromosomes in the determination of sex in insects. Sex chromosomes (Y or X) are important in this respect. The rest of the chromosomes in a cell comprise the autosomes. Sex chromosomes occur in several instances as cytologically distinguishable bodies, which may sometimes be designated as heterosomes. The body cell is generally spoken of as diploid, with the chromosome make up of $2n$. In simple examples (*Drosophila* in general) $2n$ will have one or one pair of heterosomes ($2n$ XX, $2n$ XO and $2n$ XY) when paired it may be XX, or XY and when single it is XO, O signifying the absent chromosome. Generally the female shows a double X (XX) and a male may either be with XY or only with an X (XO). The germ cells that arise from these diploid cells will be with half the chromosome complement, i.e. n X, or n Y or n O. As the female has XX, the gametes that arise will all be with one X and so this sex is distinguished as homogametic. The male may be either XY or XO, and the germ cell produced may be one of the two different types: one distributing X and Y into separate gametes and the other distributing X to one gamete only, the other gamete being without it. The male here is known as the heterogametic sex. In Lepidoptera the female is heterogametic and the male homogametic (XY in these insects being designated as WZ).

The individuals originate as zygotes, the zygote formed by fusion of an X-bearing egg with an X-bearing sperm growing into an XX female; males are produced by a fusion between the X-bearing egg and a Y-bearing (or sex chromosome unrepresented) sperm, forming an XY or XO.

This simple arrangement of sex chromosomal determination of sex is, however, not universal. It has been discovered that a balance between the autosomes and the sex chromosomes also plays decisive roles in deciding sex. In *Drosophila* itself, a female may be XX (usual) with 2*A* (autosomes); 3*A* XXXY, 3*A* XXXYY, 2*A* XXYY also develop into females; a male may be XY with 2*A*, 2*A* XYY, 2*A* XXYY also grow into males known as supermales, and 2*A* XXX grow into a superfemale. But 3*A* XX and 4*A* XXX will grow into an intersex.

The rule which will be applicable to *Drosophila* will not be operative in other Diptera that have been investigated. In some the Y-chromosome functions as the male determiner. XX and XO will be giving rise to females, while XY will be males in insects like *Calliphora* and *Lucilia.* This has been sometimes referred to epistasis.

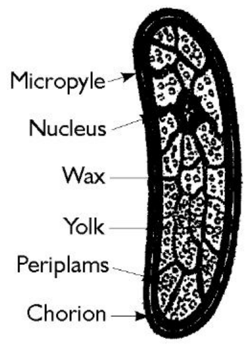
In parthenogenetic forms, the haploid eggs that develop without fertilisation give rise to males. An interesting phenomenon of chromosome elimination occurs in paedogenetic cecidomyiids like *Heteropeza.* The larva parthenogenetically produces daughter larvae, but later the two sexes develop, and maleness is influenced by food. Elimination of chromosomes occurs in the nuclei of the body cells, females retaining ten chromosomes and the males five. The males arise from haploid cells here. In the scale insect *Pulvinaria* maleness has been associated with the chromosomal regions becoming inert and heterochromatic while the euchromatic conditions tend to produce females.

Several complications in genetic sex-determining mechanisms have come to light, and a generalisation of any type has become practically impossible in briefing sex determination mechanisms in insects.

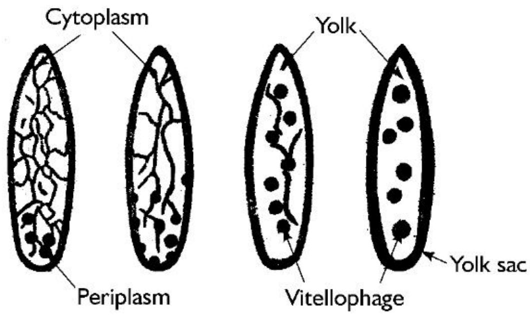
◆ Chapter 23

Development, Growth and Metamorphosis

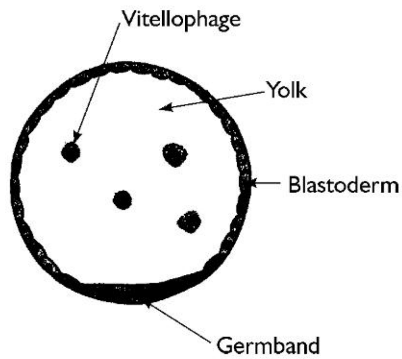
The eggs of insects present remarkable variations in shape and size. They may be laid singly or in groups enclosed in gelatinous masses, or in the ground as egg-pods, or retained in egg cases or oothecae. The eggs may be spherical, oval, elongate, disc-like or barrel-like. They are usually covered by two envelopes (Fig. 23.1). The chorion in the egg-shell is often rigid when laid in exposed surfaces or thin and flexible when laid in sheltered situations. The chorion is developed from the follicular cells of the ovary and it frequently shows two layers, an outer exochorion and an inner endochorion. The vitelline membrane, the second envelope of the egg is often a delicate structure developed from the cell wall of the egg. It rarely has a double layered, tough and thick texture as in some Diptera. The chorion is strengthened by several layers of proteinaceous or lipid material and mostly shows surface sculpturing. A cement-like covering secreted by the colleterial glands helps to fasten the eggs to the substratum. One to many minute openings, the micropyles may be present on one end of the egg, presumably facilitating the entrance of the sperm. The coverings of the eggs serve to prevent loss of water and many eggs have waterproofing of waxy layers. Diverse respiratory mechanisms also exist in the eggs from a thin chorion to a porous air filled layer below the egg shell, communicating with the exterior through



▲ **Fig 23.1** *Diagram of an egg showing its parts (R.F. Chapman, 1969)* respiratory filaments as in the eggs of *Laccotrephes* and *Ranatra*.



▲ **Fig. 23.2** *Four stages of formation of the blastoderm (ibid)*

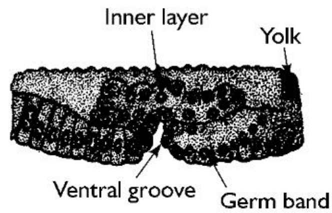


▲ **Fig. 23.3** *Transverse section of a developing egg showing thickening of the germ band (ibid)*

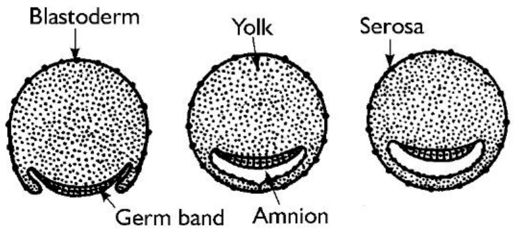
In general the egg of an insect contains a thin cortical layer of protoplasm and a dense central yolky mass. The nucleus in the unfertilised eggs lies in the central part of the egg, but on fertilisation it moves away from the centre and soon afterwards begins to divide into daughter nuclei. In most insects cleavage is superficial, the cleavage nuclei undergoing mitosis, till a large number of nuclei are formed. Each nucleus separates itself from others by migration and each is surrounded by a stellate mass of cytoplasm which is often called energid. Therefore in the very early stages the egg is a syncytium of the yolky cytoplasm, with the scattered cleavage nuclei. The cleavage nuclei then move towards the peripheral cytoplasm forming a continuous outer layer surrounding the yolk termed the blastoderm (Fig. 23.2). With the formation of the blastoderm the cells on the ventral side of the egg become columnar, forming the ventral thickening or germ band (Fig. 23.3). The remaining cells of the blastoderm form a flattened epithelium. In many insects the germ band assumes a variety of shapes and may remain on the surface of or get sunk into the yolk.

In the eggs of several Hymenoptera showing polembryony as in *Platygaster*, total or complete segmentation is seen. In Collembola such as *Isotoma cinerea* and *Anurida maritima*, segmentation is initially complete and is subsequently followed by a more superficial cleavage. The viviparous Strepsiptera have incomplete cleavage in view of the large amount of yolk.

Cleavage is followed by some of the cells of the germ band moving towards the yolk either by invagination, or by proliferation (Fig. 23.4), or by overgrowth of cells from



▲ **Fig. 23.4** *Proliferation (Locusta) to form two layer embryo* the inner side of the germ band, resulting in a two-layered embryo. The outer layer gives rise to the ectoderm and the inner cell mass or mesentoderm to the endoderm and mesoderm. The margins of the blastoderm near the germ band grow backwards over it from all sides and finally meet in the middle, forming a two-layered extraembryonic covering, an outer amnion and an inner serosa (Fig 23.5). The amnion is continuous with the margins of the germ band and while it covers the embryo, the serosa encloses both the yolk and the embryo. While two distinct embryonic envelopes are met with in most insects, variations do exist.

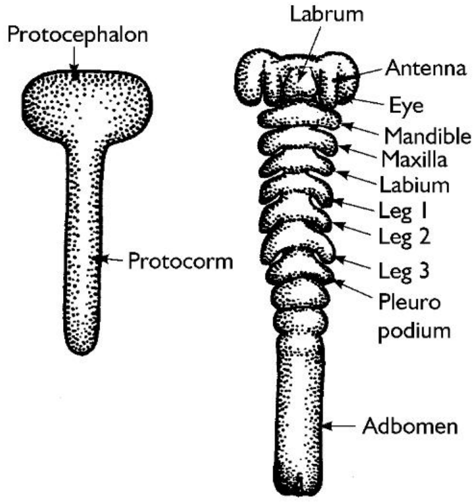


▲ **Fig. 23.5** *Sectional diagrams showing development of amniotic cavity (R.F. Chapman, 1969)*

The occurrence of a third envelope called the indusium is found in many Orthoptera, while only the amnion is present in Strepsiptera. However, in viviparous species there is also a single trophamnion serving for food absorption from the yolk or host tissues. In earwigs, some flies and many beetles, the embryo comes to lie superficially below the chorion, while in the Hemiptera the posterior end of the germ band sinks into the yolk. Side by side with these developments the embryo undergoes certain rotatory movements called blastokinensis; the embryo first moving in an arc to the dorsal region either by sliding along caudal end or by rotation along its long axis and subsequently back again to its original position.

Many opinions exist regarding gastrulation, the principal ones being those of Heymons, Hirschler and Roonwal. While all three agree that the primary yolk cells represent the primary endoderm, they differ in that gastrulation is a more extended process. According to Hirschler, Gastrulation is biphased with the development of an inner layer of secondary endoderm as a result of the formation of a gastrular furrow; and multiphased according to Roonwal, involving the further differentiation of the inner layer into mesoderm and endoderm.

At an early stage the germ band undergoes segmentation into the primary head lobes or the protocephalon and a narrower part, the protocorm or primary trunk segment (Fig. 23.6). The germ band soon elongates and with growth, segmentation becomes evident initially at the anterior end of the germ band and gradually proceeds towards caudal end. The primary head segments are the protocerebral, deutocerebral and tritocerebral lobes and the first three protocormic or primary trunk segments become fused with the primary head segment to form the future head. The latter bears rudiments of the mandibles, maxillae and labium. This has already been referred to earlier under the segmentation of the head. Of the succeeding segments of the protocorm, the next three become the prothoracic segments bearing the rudiments of legs, while the remaining segments form the abdomen, which is usually 10- or 11-segmented. There is an unsegmented telson and the proctodaeum always invaginates from it. In the very early stages of development all the abdominal segments bear lateral appendages or pleuropodia which are retained only in some primitive insects and are lost or degenerate in others before the completion of embryonic development. In the mature embryos of blattids, mantids and other Orthoptera, they appear as a pair of glandular structures on the first abdominal segments, reaching their maximum size before hatching and then disappearing.



▲ **Fig. 23.6** *Early embryos in the course of development (ibid)*

The mesodermal cells of the inner cell mass even at the germ band stage become several layers thick and get separated into splanchnic and somatic layers. Soon this double-layer becomes arranged into definite metameres separated by distinct constrictions. The drawing apart of the somatic and splanchnic layers result in a series of cavities, the coelomic cavities. As has been mentioned in the segmentation of the head, each metamere has a pair of coelomic pouches except in the acron and telson.

With the development of the germ layers, further differentiation involves the formation of the various organs and systems and the major derivatives of the germ layers in insects are:

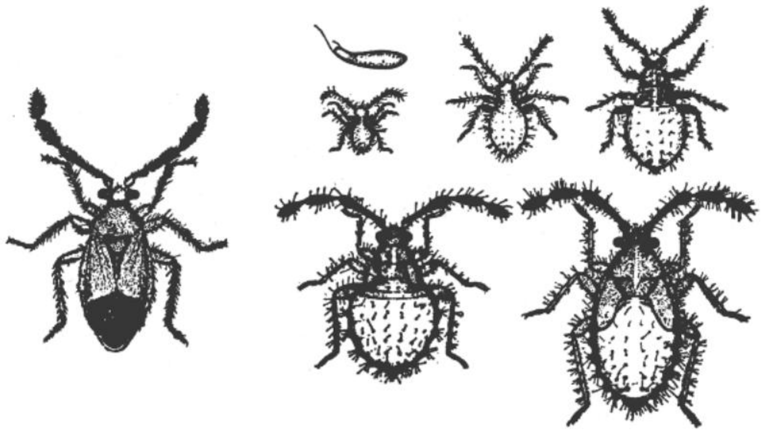
- *Ectoderm*: Chitinous exoskeleton, hypodermis, wings, common oviduct and spermiduct, corpora allata, oenocytes, stomodael and proctodael epithelia, malpighian tubules, nervous system, salivary glands, trachea, uterus, etc.
- *Mesoderm*: Blood, heart, fat bodies, paired oviducts and spermiducts, muscles, connective tissues, follicular yolk.
- *Endoderm*: Epithelium of midgut and when present of the caeca.

It may be mentioned that the form and organisation of the embryo appears to be controlled by three centres in the cortical plasma–a cleavage centre near the future head rudiment, an activation centre at the posterior end and a differentiation centre near the middle of the germ band almost approaching the region of the future thorax.

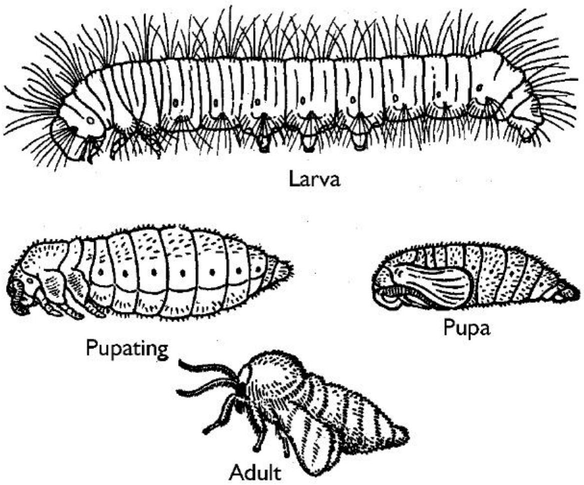
On completion of development, hatching or eclosion results and to help in the emergence of the early embryo, many insects possess spines or other hard cuticular structures serving to break through the chorion, vitelline membrane and serosa or force open the operculum.

Metamorphosis

In primitive wingless insects or Apterygota only very slight changes are brought about during post-embryonic development with each moult. Here moulting continues even after the adult stage is reached. Such insects which emerge from the egg looking like the adult in appearance and which do not have a metamorphosis, in the pure sense, are termed Ametabola. Exopterygote insects like the Orthoptera, Hemiptera, etc. have a simple metamorphosis, the young ones hatching from the egg in a comparatively more advanced stage of growth and resembling the adult in general appearance, but differing in the smaller size and absence of wings. The wings are represented by wing buds and with each moult it increases in size, becoming fully developed at the final moult (Fig. 23.7). Such insects are termed the hemimetabolous insects or insects with partial metamorphosis. The endopterygota like the butterflies and moths, flies, beetles, etc., have a more complex metamorphosis, the young ones emerging from the egg being totally different in appearance from the adult even in the nature of the mouthparts. The young one on hatching is termed a larva, which feeds, grows and moults and undergoes striking changes while becoming a pupa. This is generally a quiescent stage and from the pupa emerges the imago or adult (Fig. 23.8). Such insects with a complete or complex metamorphosis are termed the Holometabola. The Hemimetabola and the Holometabola comprise the Metabola or insects with metamorphosis.

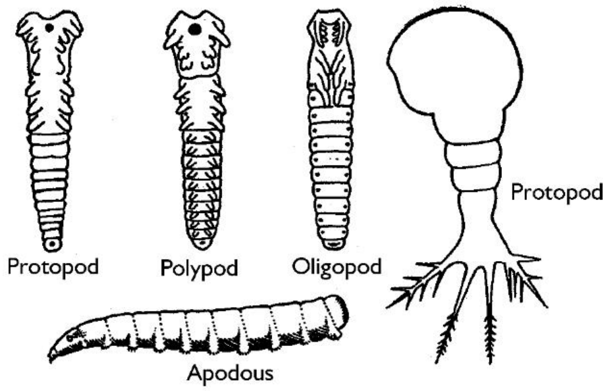


▲ **Fig. 23.7** *Exopterygote hemimetabolous post-embryonic development as in Mirid, Hemiptera (M.R.G.K. Nair, Indian J. Entomol., 1962)*



▲ **Fig. 23.8** *Holometabolous post-embryonic development in Lepidoptera (Smiths. Misc. Coll.,* **143** *(6): 1–51)*

Types of Larvae Principally four main morphological types of larvae are recognised– the propod, oligopod, polypod and apodous larvae (Fig. 23.9).



▲ **Fig. 23.9** *Types of larvae*

1. *Propod larvae:* These hatch at a very early stage of development with segments and limbs imperfectly demarcated and are characteristic of parasitic Hymenoptera.
2. *Oligopod larvae:* These are characteristic of Coleoptera or beetles with segments well differentiated and with three pairs of thoracic legs and without abdominal limbs. They are also referred to as the campodeiform larvae when they bear long

caudal cerci. They are very varied in shape with well-developed antennae and mouthparts.

3. *Polypod larvae:* These are characteristic of caterpillars of Lepidoptera, sawfly larvae (Hymenoptera) and larvae of Mecoptera. They possess both abdominal and thoracic legs and the body is elongate cylindrical, orthognathous. The abdominal legs are usually referred to as the false legs or prolegs. These larvae are also termed as the eruciiform larvae.

4. *Apodous or legless larvae:* They are characteristic of Diptera or flies, some Hymenoptera like bees, wasps and weevils. Legs are totally absent and some may possess minute fleshy lobes or hairy pads in place of legs.

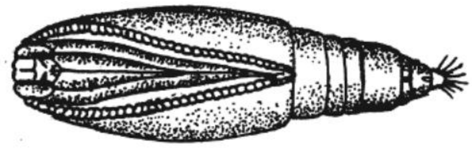
While these are the main types of larvae in general, several other kinds are also present but for the most part are only modifications of the oligopod types. Particular mention may be made of the larvae of aquatic insects like Odonata, Ephemeroptera, Plecoptera, Trichoptera, etc. In the dragonflies or Anisoptera, the larvae called naiads have adaptations for aquatic respiration in the form of tracheal gills restricted to the large rectum, its walls bearing a regular series of gill lamellae. In the Zygoptera or damsel flies, large caudal tracheal gills occur. Further, in both, there is an excellent adaptation for feeding, the labium being modified into an extensile hood or mask. The larvae of Plecoptera possess numerous tracheal gills in the shape of elongate, simple or branched clusters of fine tubes attached to the pleura of the thorax and also on to the legs. The ephemerid or mayfly larvae have tracheal gills on the first seven abdominal segments and these may be simple, bilobed or branched. Lastly, in the eruciiform larva of Trichoptera, filamentous tracheal gills are present and have rarely rectal blood gills, the larvae always remaining within cases.

Types of Pupae The pupa or chrysalis is the quiescent or resting stage characteristic of all insects with a complete metamorphosis. Sometimes various degrees of movement are observed and in the pupae of caddisflies, there are adaptations to help them to swim to the surface of water or as in the case of the gnats, the pupae swim vigorously. Three types of pupae are recognised:

1. *Pupa exarata or free pupa (Fig. 23.10):* The legs, antennae and wing rudiments lie free and are not soldered to the body. This type is characteristic of all Hymenoptera, Neuroptera, Coleoptera and Trichoptera.

▲ **Fig. 23.10** *Exarate pupa of a wasp*

2. *Pupa obtecta:* The legs, antennae and wings are soldered or fastened to the body of the pupa along its length (Fig. 23.11). This type characteristic of Lepidoptera and cyclorrhaphous Diptera.



▲ **Fig. 23.11** *Obtect pupa of a moth*

3. *Pupa coarctata:* The last larval moult skin is retained and becomes hardened to form a protective case for the pupa which is developed inside it. This case is referred to as the puparium, which is almost barrel shaped and is segmented, but there is no outward sign of the legs, antennae or wings. Such pupae are very characteristic of cyclorrhaphous Diptera.

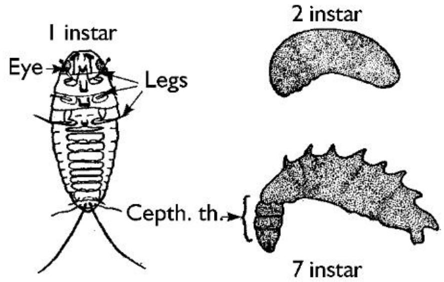
In many insects (as in mayflies) there exists another instar known as the prepupa, a stage preliminary to the formation of the pupa with visible changes for the first time outside the body. Several insects retain parts or nearly complete portions of previous moulted skin, this is called the pharate condition.

In order to protect themselves during the pupal stage, the larvae of many insects construct cocoons made of silk or other material like particles of mud, tiny wood pieces, hairs, etc., as in Trichoptera.

Principal Changes During Metamorphosis Striking reconstruction of epidermis with the production of fresh tissues as a result of new cell division and death of old cells is very characteristic of metamorphosis. In many the rudiments of adult organs are evident even in the very early stages in the form of groups of undifferentiated cells or imaginal discs, mostly seen as thickenings of epidermis. An essential aspect of the histological changes during metamorphosis include histogenesis or growth and histolysis or cellular breakdown, which serves in the removal of purely larval tissues. While histogenesis includes active division of cells by mitosis, histolysis involves the breakdown of larval tissues and the path played by phagocytes in the blood in the actual breakdown is much disputed, though they are definitely known to remove dead cells through digestion or autolysis. In some insects this autolysis takes place through chemical means, the haemocytes playing no part.

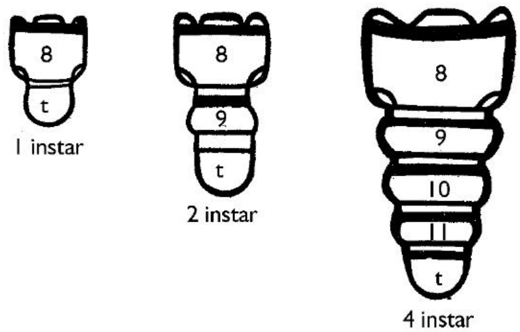
An important aspect of metamorphosis is the growth, the stage between the moults being termed as an instar. Pronounced growth or a period of active growth marks the period before a moult. The amount of growth brought about at each moult has been expressed in terms of certain laws such as Dyar's law which states that the head capsule grows in geometric proportion, the width increasing at each moult by a constant ratio. Another law of growth is Przibram's rule whereby during each instar the weight is doubled and at all moults there is an increase of all linear measurements by a constant ratio. While these laws presuppose uniform growth, in many insects the growth is not uniform or harmonic but disharmonic, several parts growing at varied rates in relation to the growth rate of the body as a whole. Such a growth has been termed as allometric or heterogonic growth.

In some insects like the meloid beetles, Strepsiptera, etc., the larval stages are interesting in that they show different forms. This is spoken of as hypermetamorphosis. In Strepsiptera, the egg hatches out as an active triungulin larva which lurks among flower lobes for a passing host on to which it clings, later it becomes endoparasitic and loses limbs and becomes saccular. Towards the late stages the larva differentiates an anterior cephalothoracic region (Fig. 23.12). This phenomenon is described as heteromorphosis.



▲ **Fig. 23.12** *Heteromorphosis in Strepsiptera (R.F. Chapman, 1969)*

One peculiar phenomenon shown by the ametabolous Protura is called anamorphosis (Fig. 23.13). Here during larval development three new segments are added on to the last abdominal segment (eighth) and in front of a telsonic lobe (t).



▲ **Fig. 23.13** *Anamorphosis in Protura (ibid)*

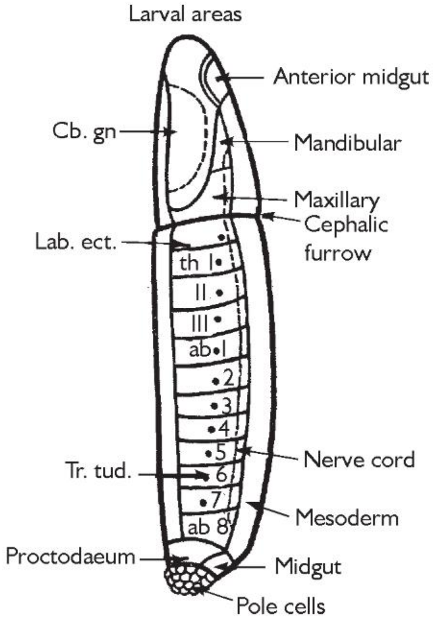
Hormones and Metamorphosis: Kopec 1922, first demonstrated that moulting is brought about by hormones in *Lymantria* and it was left to Wigglesworth to establish the complete significance of this process. Metamorphosis or larval-pupal-adult transformation serves a dual purpose, viz. moulting and change of form. During moulting or ecdysis, the formation of new exoskeleton begins before the old cuticle is shed. Under the influence of the exuvial fluid or moulting fluid secreted by special glands of the hypodermis, the lower layers of the old cuticle are absorbed.

* Kopec, 1922. *Biol. Bulk.* **42:** 322–42.

Post-embryonic development of insects appears to be under hormonal control, in particular the larval-pupal-adult moults. Different stimuli come into play in various insects to cause moulting. Distension of the abdomen after a meal may provide a stimulus in insects like sucking bugs and the stimuli is carried to the brain by nerves. Stretch receptors may also be present in the abdomen or pharyngeal wall and stimuli of these also produce nervous impulses. In normal metamorphosis the cyclical growth and moulting takes place through the agency of the brain or prothoracotropic hormone secreted by the neurosecretory cells of the brain, and the prothoracic gland hormone or ecdysone, produced by the prothoracic glands. The prothoracic gland is under the control of the brain hormone and ecdysone initiates the moulting process and acts on the various tissues, thereby starting the growth process. Its primary effects appear to be at the nuclear level. In addition to these hormones, viz. the brain hormone and ecdysone, a third hormone, the juvenile hormone (JH) or neotenin, secreted by the corpora allata, appears to promote larval development and prevent metamorphosis. In other words larval characters are maintained through the action of the juvenile hormone, occurring in high concentration, so that at every moult, the larval features are maintained. On the other hand, when the juvenile hormone concentration falls and ecdysone is in higher concentrations, pupal transformation results, while in the total absence of the juvenile hormone, it differentiates into the adult form. Evidence relating to the action of juvenile hormone on the epidermal cells has shown that they secrete a larval cuticle when in high concentrations and in the presence of the prothoracic gland; a pupal cuticle when in low concentrations and an adult cuticle in the absence of juvenile hormone.

Experimental Embryology of Insects

Prior to morphological differentiation in insect eggs, there occurs the process of primary chemo differentiation which determines the fate or the course along which the different regions of the egg are to develop. As a result of studies regarding the capacity of insect eggs to reorient or readjust themselves following injuries inflicted through cauterisation, puncturing, constricting or centrifuging when compared to normally developing eggs, it has become possible to classify them into three distinct categories: the indeterminate or regulative, the incompletely determinate and the determinate or nonregulative types. Indeterminate eggs are not predetermined at the time of fertilisation and it is only after the formation of the blastoderm that the separation of the prospective regions takes place as in Odonata and Hemiptera. In the determinate type the various regions are fully predetermined (Fig. 23.14). Self-differentiation is evident after fertilisation and they are therefore not capable of development beyond their prescribed limits as in Diptera. The incompletely determined eggs show a graded series in between the first two types and are capable of a certain amount of regulation if interfered with in the early stages of development as seen in some Coleoptera and Hymenoptera.



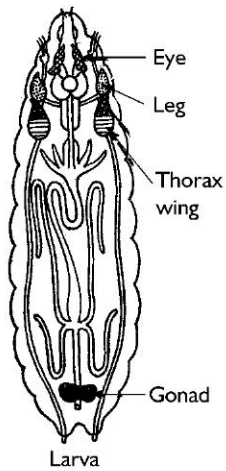
▲ **Fig. 23.14** *Presumptive larval areas of Bactrocera embryo (D.T. Anderson, Ann. Rev. Ent., 11, 1966)*

In all insect eggs there is an activation center located at the posterior end of the egg and its action is vital for germ band development. The proper functioning of the activation centre depends upon the interaction of the cleavage nuclei and the region of the activation centre. Experimentally, if by a constriction, the cleavage nuclei are prevented from reaching the region of the activation centre, no development takes place in spite of the anterior region continuing to live and undergoing cleavage. A substance, which is the product of the interaction between the cleavage nuclei and activation centre, diffuses forwards into the yolk system and activates the differentiation centre. In general, it is from the future thoracic region that differentiation proceeds both in the anterior and posterior directions, but in some cases as in the honeybee eggs, this centre for embryonic differentiation commences near the anterior end. In insects where this centre lies in the thoracic region, the differentiation centre extends from the maxillary to the second thoracic segment., The normal functioning of the differentiation centre is not possible if this region of the egg is constricted. It has been further demonstrated by the pioneering work of Siedel on the eggs of the damselfly *Platycnemis*, that the differentiation centre is dynamic and not static, because, killing of a girdle of cells in front of or behind this region where normal visible differentiation commences, causes a shift in the position of the initial differentiation centre backwards or forwards respectively.

Potency regions are demarcated for example, in the 12 hr blastoderm of the honeybee egg, so that a given region develops as a whole and during the 12 to 24 hr period there occurs a shift of these potency regions indicating a redistribution of the chemodifferentiation materials as development progresses. Siedel's work on the blastoderm plan and the changes undergone during the formation of the embryo in the indeterminate eggs of *Platycnemis*, shows that there is a shortening of the embryo alongside with the onset of activity of the differentiating centre. During this time the thoracic region increases in length, due to the movement of materials towards the region of the activation centre and also due to the entire presumptive embryo being drawn towards the posterior end of the egg. In other words, the head and abdominal areas contract, but the thoracic region elongates. The embryo moves posteriorly and sinks into the yolk.

At the posterior end of the egg is a specialised protoplasmic bit called pole plasm, and this is seen in Diptera, Coleoptera and Hymenoptera. Cleavage nuclei migrate into this to give rise to pole cells and this is a device to help in chromatin retention which otherwise will be eliminated in the body cells that develop. In nematocerous Diptera these cells give rise to gonads.

Work on the role of hormones in differentiation and development has thrown some light on the problem of insect morphogenesis. In insects like cyclorrhaphous Diptera, embryonic cells could be conveniently grouped into two categories, viz. those that are destined to give rise to larval body and those that remain embryonic to resume development at the time of pupation (Hadorn, 1965), the latter form what comprise the imaginal discs (Fig. 23.15). While division and growth in size of the latter could continue in the early stages of life history, they remain undifferentiated until metamorphosis. It is the juvenile hormone that blocks this differentiation and the drop in level of this hormone 'deblocks' the differentiation as pupation sets in and it has been suggested by Whitten (1968)* that the juvenile hormone represses the sets of genes required for differentiation.



▲ **Fig. 23.15** *Imaginal discs of larval dipteran (adapted from Hadorn, 1965)*

When deblocking occurs, the imaginal discs differentiate. The differentiation that ensues follows a definitive path, and the wing disc gives rise to a wing or a leg disc to a leg. But the potentiality of a disc cell mass is not absolute because repeated 'blocking' may result in what has been called transdetermination, as for example, germinal disc after repeated blocking by serial transplantation into larvae may differentiate into a leg or a wing. This phenomenon of transdetermination discovered by Hadorn, has been studied to some extent in *Drosophila*.

* Metamorphic changes in insects, *Metamorphosis*. eds. W. Etkin and L.I. Gilberk, Appleton–Century–crofts, N.Y.

◆ Chapter 24

Rhythms

Insect behaviour is considerably influenced by rhythms. Many activities like locomotion, orientation, sensory reactions, and seasonal behaviour, are all controlled in a timed sequence and the time-measuring involved in these phenomena is spoken of as a biological clock. A rhythm may be defined as a periodically repeated variation in activity, under the control of an inborn measuring sense. Feeding activities, ovarian activities, etc., which form a sequence of events, repeated during the life of an individual and involving a change in behaviour or physiology are defined as cycles. A recurrent pattern of activity in relation to time is referred to as periodicity–24-hour (diel), lunar or annual. Usually endogenous (innate, genetic response component) and exogenous (responses to immediate environmental stimuli) components in rhythmic periodicity have been stressed in rhythm sudies.

Several insects exhibit diurnal rhythms of activity. Rhythms typically having a period with a counterpart in natural environment (i.e. 24-hourly rhythm) is called a circadian rhythm (sometimes merely diurnal). *Periplaneta* becomes active by nightfall; in actual fact an increase in activity sets in just before it gets dark and the insect will continue to be active despite artificial light provided to them. Thus it shows that activity is promoted not by mere onset of darkness. An earlier interpretation by Harker[1] has attributed this activity to be promoted by neurosecretory release from the cells of the subesophageal ganglion, and secretory cells possessing a 24-hour rhythm, but this has been questioned by Brady,[2] and Roberts[3] has implicated brain cells in this activity. In the beetle *Carabus* the daily rhythm has been attributed to the corpora allata.

[1] Harker, J.E. 1960. *Cold Spring Harbor Symp. Quant. Biol.* **25**: 279–87.
[2] Brady, J. 1974. The physiology of insect circadian rhythms. *ADV. Insect physiol.*, **10**: 1–115.
[3] Roberts, S.K. de. F. *et al.* 1962. *J. Cell. Comp. Physiol.,* **59**: 175–186.

In the operation of rhythm, it is suggested that an interval time controls the periodic occurrence of a discrete event as for example eclosion of adults. Interval time has been linked up with the diel (24 hr); but longer durations have been also known as in lunar emergence shown by *Clunio*, annual emergence of *Anthrenus*, etc. Of unknown environmental influences are the production of sexuales in the clones of the aphid *Megoura*, and the mass emergence of *Megacicada* once in every 13 or 17 years. Mating rhythm is seen in several insects, midnight mating peaks in *Antheraea* and *Hyalophora*, early morning mating in *Clysia* and early night mating in *Polychrosis*.

Rhythms influenced by environmental factors of special types are also known. Previous experience has been cited resulting in summation of subthreshold stimuli as in dual peaks in the flight of Odonata at 40° N latitudes, multiple biting periodicities of *Aedes agypti*, and anthropophilic insects like mosquitoes which feed during the second half of night when human beings asleep.

In noctural moths like noctuids, there is a rhythmic migration of eye pigments. The eye of *Pyrausta* turns light-adapted about half an hour before sunrise, and dark-adapted within an hour before sunset. The rhythm is persistent for several days if experimentally interfered with by providing complete darkness. While in crustaceans eye pigments respond to hormones, the insectan eye pigment movement is described to be not under known hormonal control. It is mentioned that it may be neural.

Sensitivity in the compound eye of *Dytiscus*, not exclusively due to pigment movement, also shows a rhythm. The dark-adapted eye is 1000 times more sensitive than the dark-adapted day eye. Similarly the light-adapted night eye is less sensitive than the light-adapted day eye.

Physiological colour change is a rapid chromatic adaptation brought about by the regulation of the pigments of the chromatophores. This has been found to show rhythmic changes for example in *Carausius*, the insect appearing greenish during day time and black during night; at twilight it is grey. Larvae of *Corethra* have two pairs of pigmented tracheal sacs serving a hydrostatic function; the pigments here concentrate on a light background and disperse on a dark background. The latter is more an adaptation to suit the colour pattern of the environment and is thus not a true rhythmic change of colour, while that of *Carausius* is more attuned to a rhythm. This colour change is under the control of the juvenile hormone which induces the development of the green colour.

Two views are maintained regarding the mechanisms involved; one postulates an external timing hypothesis and the other an internal autonomous timing hypothesis.

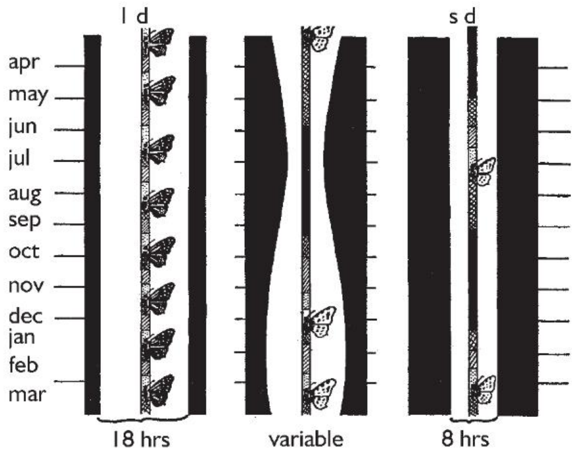
◆ Chapter 25

Diapause

In the life history of several insects, there is a period of apparent cessation of development which is distinguished as diapause. This is a device to survive adverse conditions and is most often observed in forms that live in temperate climate. This adaptive dormancy is not immediately referable to the unfavourable environmental conditions, and in this respect is distinguished from quiescence which is dormancy, directly referable to conditions of the environment. Water contact breaking the quiescence of the gall midge *Schizomyia macarangae* is different from the break of diapause of the wheat blossom midge *Sitodiplosis mosellana*; the latter is an example of diapause.

In the temperate regions diapause is an overwintering device; in tropics it helps in tiding over the severe hot weather. Generally diapause manifests only during one stage of the life history. *Melanoplus* and *Bombyx* show egg diapause; *Cydia* shows larval diapause, several Lepidoptera (*Eupterote, Platysamia*) show pupal, and *Leptinotarsa* and *Nebria* show adult diapause. All individuals of every generation enter diapause; this is obligatory diapause resulting only in a single generation (univoltine) as in *Orgyia* eggs which hatch in May after seven months. Where diapause affects only some members of a generation, it is distinguished as facultative, resulting in two or more generations in a year - multivoltine cycle. Experiments have shown that the difference between the two types is only one of degree as diapause could be prevented by providing extreme conditions. However, in *Bombyx mori* the strains without diapause have been genetically differentiated.

Day length affects reproduction in insects. The autumn days are short and the summer days are long in the regions outside the tropics. The period of day light (photoperiod) is a deciding factor in inducing diapause; forms like *Pyrrhocoris* will go into diapause by short day treatment. Prolonged illumination even in winter will prevent diapause in *Culex pipiens*. Most temperate insects develop without diapause in prolonged illumination, these are known as long day insects. *Bombyx* is an insect which enters diapause when exposed to long day. When bivoltine strain is exposed to long days the next generation eggs enter into diapause. Eggs exposed to light for 14 hours or less will lead to the adults emerging from them to lay non-diapausing eggs. The insects which grow without diapause when the critical stage is exposed to short day length are described as short-day insects. The larva of *Euproctis* undergoes diapause when exposed to long or short photoperiods, but shows no diapause when reared in a day length of 16 to 20 hr. In the butterfly *Araschnia* the dark form arises when the larvae are exposed to long day and the pale form arises from caterpillars exposed to short day; the latter is the result of a pupal diapause (Fig. 25.1).



▲ **Fig. 25.1** *Effect of photoperiod on the butterfly* Araschnia: *long days (18 hr) produce dark forms, short days (8 hr) produce pale forms after a pupal diapause* (M. Gersch, 1964)

It is suggested that the ocelli and eyes are not involved in photoperiod perception. In larvae the stemmata have been implicated, and in the aphid *Megoura* the light directly influences the neurosecretory cells of the brain. In most cases it is the short wavelengths that induce the photoperiodic responses.

Evidences have been presented to suggest a relation between diapause and the quantity and quality of food. Feeding on senescent leaves induces diapause in *Leptinotarsa* adults. It is also mentioned that photoperiod affects food plants and in turn affects insects to enter into diapause, as for example in the cabbage rootfly *Erioischia*.

High temperature inhibits and low temperature enhances diapausing tendencies, especially in temperate zones. Insects which are widely distributed show adaptations under different photoperiods. In South Russia, *Acronycta* diapauses when the day length falls below 15 hr, while in Leningrad it shows diapause which is prevented only if the photoperiod is over 18 hr. *Bombyx* is a unique example which diapauses when temperature is high.

Diapause manifests in various ways. In the egg it is as delay in development, in the larva as a quiescent, non-feeding stage, in pupa as a prolongation of pupal period, and in the adult as delay in reproduction coupled with nonfeeding and immobile state often showing arrestation of egg growth and yolk deposition. There is a build-up of reserve in fat bodies prior to diapause together with a reduction in the proportion of water in the insects. It does not necessarily follow that this stored material is used up during diapause; in fact only part is used up except in rare cases like that of female *Culex pipiens.*

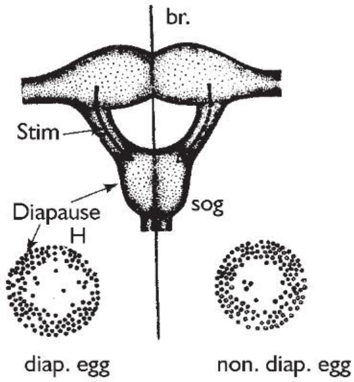
Reactivation or resumption of arrested development is sometimes called diapause development. Among the environmental factors, temperature plays a very important role here. The role of water in diapause development is not clearly understood. Also photoperiod plays a part in diapause development in some examples like larval *Dendrolimus.*

Briefly stated, diapause is controlled in the larval and pupal stages by the hormone ecdysone; its deficiency resulting in arrestation of moulting and growth. The diapause in adults is due to failure of the production of juvenile hormone by the corpora allata preventing egg growth. Both ecdysone and juvenile hormone fail to get formed due to the inactivity of the neurosecretory cells of the brain. This inactivity of the secretory cells of the brain has been attributed to influences from light, temperature and other stimuli. Lees* suggests that the accumulation of food materials inactivates the neurosecretory cells, while it has also been claimed that interference with electrical activity of brain cells induces diapause; both these views have been criticised.

In *Bombyx*, a diapause-inducing hormone has been postulated arising from the neurosecretory cells of the suboesophageal ganglion of the parent. An antagonistic hormone has been described to be produced by the corpora allata. The production of the two hormones is under the control of the brain and the balance between the hormones decides the degree of differences in the eggs produced. It is also suggested that the suboesophageal ganglion is stimulated by the neurosecretory cells of the brain, and the absence of the latter

* Lees, A.D. 1955. *The Physiology of Diapause in Arthropods.* Combridge Univ. Press, Cambridge, p. 150.

will bring about a checking effect on the elaboration of the diapause hormone (Fig. 25.2) from suboesophageal centre.



▲ **Fig. 25.2** *Diagram indicating control of egg production in Bombyx mori. The suboesophageal ganglion (neurosecretory cells) when stimulated by the brain will produce diapausing eggs, otherwise non-diapausing eggs are formed (ibid) br–brain, sog-suboesophageal ganglion, diapause H–diapause hormone, diap. egg-diapausing egg, non-diap. egg-non diapausing egg*

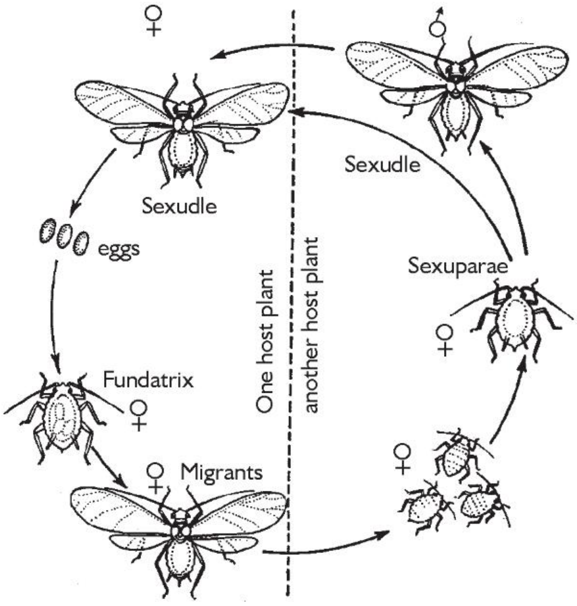
◆ Chapter 26

Biology of Reproduction

Parthenogenesis

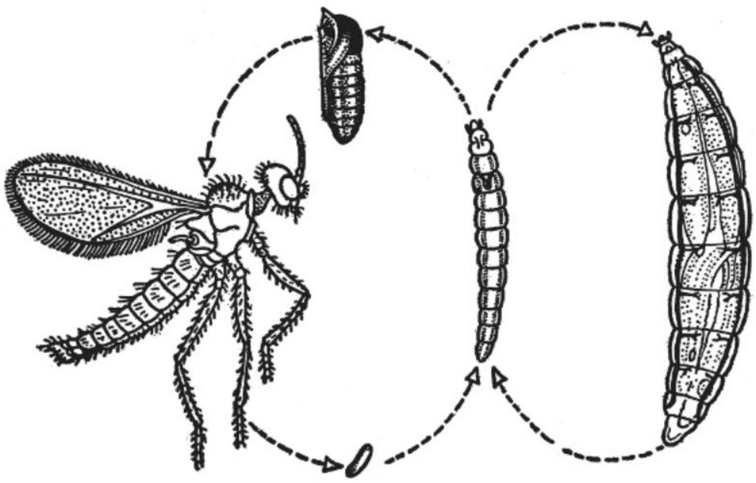
Development of unfertilised eggs occurs in a wide variety of insects. This is known as parthenogenesis. The offspring thus produced are called parthenotes. This phenomenon is also a mechanism of sex determination. Though this occurs in several groups, it is mostly met with in species of phasmid (*Carausius*) Homoptera (aphids and coccids), Psocoptera (*Psocus*), Lepidoptera (*Solenobia*), Diptera (including *Drosophila* sp.), Coleoptera (curculionids) and Hymenoptera (a large number of genera). The parthenotes may be males, as in Hymenoptera, or females as in aphids.

Thelytoky involves parthenogenesis-producing females, and is met with in a wide variety of insects (aphids for example) and is the method of reproduction preferred in conditions of abundance or favourable weather. In many Aphidoidea (Fig. 26.1) several thelytokous generations alternate with a sexual generation. Those that are described as fundatrices, virginoparae emigrantes are thelytokous, while sexuparae produce either male or female sexual individuals. Thelytoky here is controlled to some extent by photoperiod and temperature: for instance, under long photoperiod (16-18 hr) and raised temperature, 258 generations reproducing by thelytoky in *Aphis fabae* have been reared. In Hymenoptera like *Neuroterus* fertilised eggs produce females which become thelytokous. Male producing parthenogenesis (Arrhenotoky) occurs often at a critical stage in the generations of the life history which otherwise reproduce by thelytoky. In forms like *Apis* the drones are produced as parthenotes. In *Icerya* males arise as parthenotes, but the majority of the population exists as hermaphrodites.



▲ **Fig. 26.1** *Simplified scheme showing reproduction of aphid on two host plants*

Gall midges show larval parthenogenesis called paedogenesis (Fig. 26.2). Five hundred paedogenetie generations have been maintained in *Heteropeza* and it has been found that sexual forms could be obtained whenever necessary by disturbing experimental conditions, like limiting quantity and changing quality of food.



▲ **Fig. 26.2** *Reproductive cycle of Miastor. Usual cycle on left paedogenetic cycle on right (adapted from Pagenstecher year)*

Oecophylla laticauda workers lay two types of eggs–small ones growing into females and large ones giving rise to males parthenogenetically. Production of both sexes of parthenotes is described as dueterotoky.

The cytology of these reproductive mechanisms has been well studied and thoroughly reviewed. Suppression of meiotic phenomena, or fusion of polar and egg nuclei have been seen to be characteristic in many of these examples. Pseudogamy (gynogenesis), occurs in *Luffia* where the sperm only just penetrates and in *Ptinus* if mating occurs between two different species. Polyploidy has been recorded in parthenogenetic races of the moth *Solenobia* and in some weevils.

Oogenesis

Comparatively little information is available on differentiation of oocytes. Two types of cells could be distinguished–the egg cell proper and the trophic cells–the latter are responsible for nourishing the egg. Ovarioles are conventionally categorised into three types depending on the relationship between the two–panoistic, polytrophic and telotrophic.

In recent years the formation of yolk in egg cells (vitellogenesis) has been extensively investigated. The bulk of information relates to the development of proteinaceous yolk; some isolated findings on yolk of other types are also known.

Secretion of lipids into egg cell is the least known, but nurse cells have been seen to contribute to the lipid content of the egg in *Drosophila* and that juvenile hormone in some way is involved in the formation of lipid yolk in eggs of *Leucophaea.*

Labelled H^3-glucose has been found to move into the oocyte of *Apis* within a period of 3 minutes of administration, which indicates that this cell itself is involved in carbohydrate synthesis. It has also been found that this occurs only after the synthesis of protein yolk. Protein yolk is synthesised in the oocyte or get incorporated into it from the blood.

Oocytes of panoistic ovariole containing lampbrush chromosomes and multiple nucleoli involved in RNA synthesis at a high rate get the yolk synthesised within themselves. Nucleolar extrusions have been also observed and may be the RNA here is associated with synthesis of yolk protein. This is so in cockroaches. More definitive proof of this has been adduced in *Drosophila* whose RNA from the nurse cells mediate in synthesis of egg proteins.

Immunological techniques employed in studies on yolk synthesis, have revealed that in *Leucophaea* blood serum proteins get into maturing oocytes. Oolemma folds of the oocyte of *Periplaneta* grow as pinching lobes to nip off yolk spheres into the egg from blood proteins. Flourescein-labelled antibodies have shown the pathway of this movement–the material from blood does not pass through follicular epithelium, but through gaps in the brush border of the egg cortex by a process of pinocytosis. This has been found in several forms like *Periplaneta* and *Rhodnius*.

However, it has been found that the follicular epithelium also sometimes possesses machinery for imbibing proteinaceous matter as in *Gryllus*. In early phases of egg maturation this may be the method of yolk build-up. Or, it might also be that this layer lays down the vitelline membrane and as the membrane has similar imbibing machinery it may aid in protein transfer and synthesis.

Telotrophic ovarioles carrying nutritive cords to eggs as in Hemiptera or nurse cells in close association with egg as in *Musca* have a positive role to supply protein and in the synthesis of yolk. It is quite likely that a variety of mechanisms do exist in insects and that more than one method may occur in one species.

Follicular content after egg release forms a corpus luteum which as is so far known, reabsorbed in all cases.

Egg maturation is under the control of the corpus allatum and the juvenile hormone is known to have gonadotrophic properties. Earlier experiments showed that removal of corpora allata will prevent maturation of eggs and reimplantation will restore normalcy. Many species of insects have been studied by different workers, since the finding of the gonadotrophic function of corpus allatum in *Rhodnius* (Wigglesworth, 1936),* and they have all provided confirmation. However, in some Lepidoptera and in Phasmida, allatectomy does not prevent egg maturation. Even isolated abdomen shows egg maturation in the ovaries. A reduction in the output of eggs has been recorded in allatectomised moths and stick insects. Among Lepidoptera, *Pieris* is the only insect where corpus allatum has been found to be essential to the maturation of egg.

During the period of egg growth, in several insects the corpora allata vary in size due to increase in the volume of cytoplasm. The nucleo-cytoplasmic ratio of the gland is taken to indicate the nature of its activity. But it is also known that removal of ovaries from a female will also increase the size of the gland. It has been suggested that the increase in size of the gland may be due to increased activity but no proof of that has been adduced yet, although the reduced nucleocytoplasmic ratio may be indicative of secretory activity.

The activation of the corpora allata has been ascribed to nutritional factors and feeding stimuli and internal nutritional milieu, mating, and stimuli from environment like photoperiod, chemical and group factors. In mosquitoes the females require a blood meal

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* Wigglesworth, V.B. 1936. *Quart. J. Mic. Sci.* **79**: 91–121.

to develop the eggs. A full meal is believed to press the underlying ventral nerve cord helping to send signals to the brain which in turn activates the corpus allatum. The ovary is thereby influenced to mobilise proteins and eggs enlarge.

The inhibition of corpus allatum has been suggested to be under hormonal or neural control or both. Neurosecretory interventions have been found to operate in the effective stimulatory or inhibitory roles played by the corpora allata in several insects like *lphita*, *Schistocerca, Tenebrio* and *Calliphora.*

The gonadotrophic hormone elaborated by the corpus allatum is the same hormone which has juvenilising action in metamorphosis (JH). One function of the hormone is to stimulate yolk deposition. The terminal oocytes of follicles grow and the accessory glands or oviducal glands of the female also get stimulated under the influence of the hormones. In cockroaches the egg case is produced by the colleterial glands and the response of these glands to the hormone is more pronounced than that of the ovary.

The corpora allata are inactivated about the time of final moult to help in metamorphosis. They resume secretory activity soon afterwards. Only when this has commenced the ovary responds to vitellogenic influence. It may also be mentioned that a gonadotrophic role has been attributed to the neurosecretory cells of the brain in insects like *Sarcophaga.*

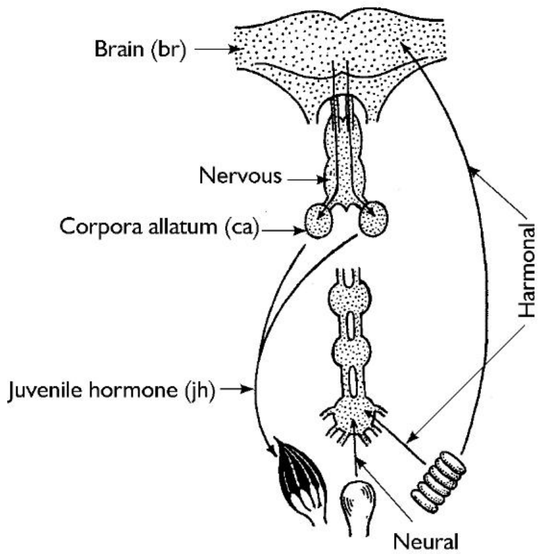
Corpora allata also exercise regulatory effect on protein metabolism. Here again neurosecretory cells of the brain have been implicated in the regulatory role as in *Calliphora* and *Gomphocerus.* Corpora cardiaca which store neurosecretory material can also have an effect on metabolism because they have been seen to raise blood protein for a short time after their implantation. Specific changes in blood proteins have been recorded in different species of insects associated with egg maturation and function of corpora allata as elucidated by ablation or reimplantation. No strict generalisation is possible about the functional role of the corpora allata; it is quite possible that the neurosecretory material from the brain and the corpora allata subserve important functions in the reproduction of insects.

Roller and Dahm* have identified the authentic juvenile hormone as 10 epoxy-7-ethyl-3,11-dimethyl-2,6-tridecadienoate. This, synthesised from cecropia moth, shows both juvenilising and gonadotrophic functions. Farnesyl methyl ether, a potent compound among farnesol derivatives, also possesses juvenile hormone properties. Strangely enough in *Pyrrohocoris* JH mimics have no authentic function of the hormone of the corpus allatum, but Roller's material has.

* Roller, H. and Dahm, K.H. 1968. The Chemistry and Biology of juvenile hormone. *Recent Prog. Hormone Res.,* **24**: 651–680.

Mating has a relation to female reproductive mechanisms. In cockroaches mating stimulates egg maturation, and it is presumed that this stimulus affects the corpora allata to promote their gonadotrophic function. In *Cimex* mating and feeding are essential for maturation of eggs. The insemination is into a spermalege which is a process of haemocoelic discharge of sperms and the sperms migrate to the oviduct within a period of 8 hr. Only when this migration is over, the corpora allata get stimulated. Mating helps in a release of neurosecretory products in locusts.

Figure 26.3 is a schematic diagram of the integration of reproduction in the female insect, outlining the complex interactions.



▲ **Fig. 26.3** *Interactions of neural and endocrine influences on reproduction in cockroaches according to (Engelmann, Gen. Comp. Endorcrin., 2, 1962)*

Male

In a large number of insects the sperms are bundled and remain so even after sperm transfer. Coupled sperms remain twisted around each other in *Thermobia* and some beetles. Sixteen sperms remain inside a sheath and such couples of bundles occur in coccids. The vibratile action of sperms within the sheath helps in propelling the bundles through the female ducts. Spermatodesms are single bundles of many sperms which either separate before transfer as in odonates or remain unchanged during transfer as in several acridids.

Males show secondary sexual characters like specialisation of wings or even presence of wings in wingless forms (glow worms), or horns and other cuticular extensions as in several beetles or specialised sensoria, stridulatory organs, etc. Because in vertebrates sex hormones play a significant role in the expression of secondary sex characters, various authors have suspected the presence of similar sex hormones in insects also. But definitive information on this aspect has been provided only by the studies of Naisse* who demonstrated in *Lampyris* a gland with androgenic properties present in the apical tissues of the testes; other workers have shown somewhat similar gland in other beetles like *Tenebrio* and *Zophobas.*

Only a few other species have been studied where some control mechanism of male maturation has been detected. In *Schistocerca* it shows up as a colour transformation from grey body and pink third tibiae to yellow body and yellow legs; this occurs more rapidly in crowded environment where other males occur side by side. The transformed individuals alone will mate. This transformation has been traced to a volatile substance liberated under the influence of the corpora allata, by mature male skin which stimulates newly emerged males through the antennae and by contact.

Sperm production is not under the control of the gonadotrophic hormone. Spermatogenesis occurs in several insects while in their late nymphal or larval stages, and so ecdysone has been cited as a possible source to stimulate sperm production. In *Drosophila*, however, spermatogenesis has been shown to occur in the absence of the glands producing ecdysone. In many species accessory glands produce materials for carrying or bundling of sperms and the corpora allata influence their activity in some species like *Rhodnius* and *Locusta.*

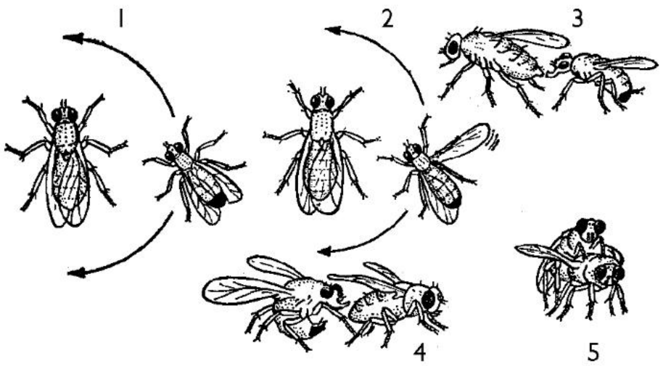
Mating

Sexual or mating behaviour in insects is an elaborate process initiating a regular sequence of activities and patterns.

Courtship has been analysed in some examples. In *Nauphoeta*, a cockroach, the mature male runs about around a group of cockroaches, and the antennae explore the members by touch. Feelers of virgin females will stimulate a male, and mutual stroking follows. The male then turns and raises his wings and at the same time lowers the abdominal tip and 'poses.' By this behaviour the secretion from the abdominal glands get wafted to the female which then crawls forwards and nibbles at the gland partly climbing on to the back of the male. The male then stretches the abdomen and grasps the genitalia of the female and

* Naisse, J. 1969. Role des neurhormones dans la differentiation sexuelle de *Lampyris noctiluca. J. Insect Physiol.,* **15**: 877–892.

twisting the body from below and the two insects come into position 'in copula.' In cockroach colonies this method will be elaborate and slow, but the nibblings (feeds) will help in bringing about successful mating. Fruitflies belonging to *Drosophila* show a different pattern (Fig. 26.4). The male starts by tapping and he taps the body of other *Drosophila* by the forelegs. The sensoria on these help the insect to identify a correct female, then he stands behind her and starts to move slowly in a circle remaining close to her and facing it. This is known as orientation. While orientating, one of the wings will be raised up at right angles to the body and vertically vibrates it. This phase is called vibration and helps to drive a current of air over the antennae of the female. A third act known as licking is also performed. The male while showing the other two activities will move behind and lick the genitalia of the female by a darting movement of the proboscis. Licking is accompanied by a quick copulatory movement when the male mounts and flexes his abdomen to effect mating. Escape movements like kick, thrust or jump may be exhibited by a female if she is unwilling, but if willing she spreads the wings and genitalia aiding in mating. Often the female does not permit mating at the first attempt and an adequate stimulation is needed to overcome the 'coyness' of the female.



▲ **Fig. 26.4** *Courtship in Drosophila. 1. Orientation, 2. Vibration, 3. Licking, 4. Initial mount, 5. Mating*

These examples show the simple and common mating patterns. However, variations occur in different insects depending on the group and the modes of life, and these are significant as isolating mechanisms.

Some apterygotes show the patterns of mating seen in myriapods and arachnids. In Collembola like *Tomocerus* the male deposits stalk bearing spermatophores on the ground in different places. When a wandering female comes into contact with the spermatophore, it stands over latter shedding a secretory droplet from the genital pore to dissolve the spermatophore, and the free spermatozoa slips into the genital opening. In *Podura*, however, the male pushes the female over to a site where spermatophores are placed. In *Lepisma* silken nest is laid over an area with spermatophores and the female is guided into this tent to pick them up.

The opposite sex is recognised at sight in several insects. Experiments have shown that usual recognition of dummies occurs in butterflies. Some lightly-coloured insects attract attention by their colouration, an example is the recognition of proper species in the two species of *Pieris* (*P. napi* and *P. bryoniae*) which occur together in the same locality at the same time. Following of flying objects is also seen as in male *Musca*, *Sarcophaga* and several odonates, and visual recognition plays a very significant role in luminous species and the forms which exhibit synchronous flashing at night. Sound production and perception of song is of value in recognising species, as in gryllids, Orthoptera, *Corixa*, etc. Pheromones form chemical means of bringing together the two sexes. The sex attractants are here significant, an account of which has already been provided. Pheromone production is generally endocrine controlled. In *Antheria polyphemus*, it has been found that mating occurs normally in the presence of the leaves of the red oak which exudes a volatile substance (trans-2-hexanal) triggering the release of the female sex attractant (Riddiford and Williams, 1967).*

Mating exhibits a rhythm. Some insects, however, do not show any rhythm as in *Iphita*; but diurnal insects mate generally during day time and nocturnal insects during night. Analysis of mating rhythms have shown that alteration in day length will affect mating detrimentally, as for example in the moth *Paramyelosis* and in the forms which generally mate during twilight. Many insects show a swarming behaviour, where a group of insects fly over one restricted area or point. This is a phenomenon often associated with emergence like mayflies, gallflies, etc., but swarming is also the time of mating as in several nematocerous Diptera, like *Culicoides*. Male swarms are invaded by females for mating as in Trichoptera.

Territorial behaviour is shown by some insects like dragonflies and wasps. In *Sphecius*, the male emerges first, establishes a small territory around the hole of emergence, and awaits a female that will wander into the territory to mate with her. Males fight vigorously over intrusions into territories. Dragonflies establish territories over ponds temporarily, and sometimes instead of fighting, ritual behaviour of displaying specialised coloured regions of the body (*Plathemis* displaying blue white of abdomen) wards off intruding males.

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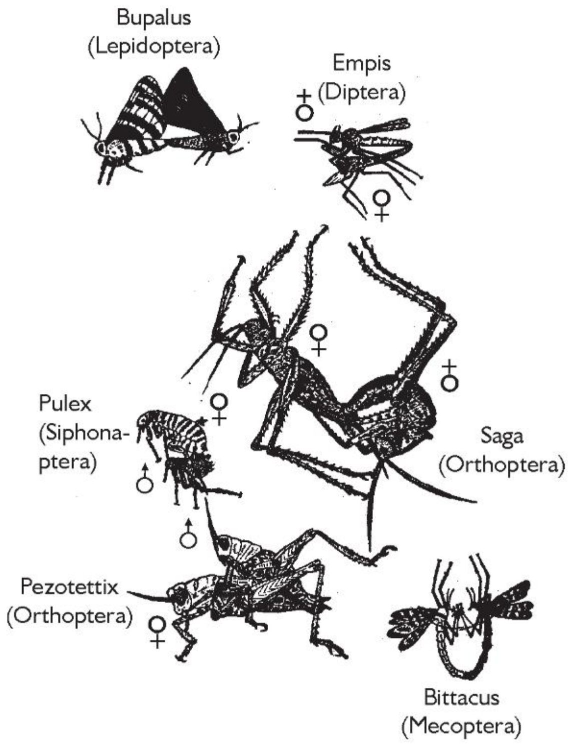
* Riddiford, L.M. and C.M. Williams, 1967, *Science* **155**: 589.



▲ **Fig. 26.5** *Mating positions in some insects (R. Jeannel, Introduction to Entomology', Boubee et Cie, Paris)*

The positions assumed by mating pairs vary considerably (Fig. 26.5). End to end mating with heads facing opposite sides (*Iphita*), parallel positions with male above (in Diptera) or female above (some Orthoptera) or with variable positions with the position of genitalia alone reversed (in Diptera) are some of the positions adopted. Specialised grasping organs are developed in some insects like the pad on the foreleg of male *Dytiscus*, or antennal holds of male collembola or the unique grasping organs of the dragonflies. Flying off 'in tandem', shown by dragonflies exemplifies this mechanism.

Some male insects exhibit an appeasement by presenting food to the female, e.g. empids, *Panorpa* etc., while the females feed on the presented food or saliva droplet, the male copulates with her. This has been developed as a ruse to escape from the female's notice, as in some mantids.

Insemination

Insemination occurs in insects whereby the sperms are transferred to the genital tracts of the females ensuring internal fertilisation. The method of deposition of spermatophores and accidental or deliberate transfer of sperms from these is the primitive method, and this has already been described. Spermatophores are deposited into the female tracts in Orthoptera, mantids, earwigs and in many other examples of other insect orders, it may occur as sperm transfer without spermatophores also. The production of spermatophores is from within the male genitalia prior to or during mating. At mating the spermatophores deposited within the female tract remain mostly as a block except in Lepidoptera where in many species the spermatophores are received into a bursa. In gryllids and *Sialis* the spermatophores are dislodged soon afterwards and eaten by the female. A secretion helps to digest the spermatophoral envelope partly in forms like *Leucophaea*, and the corpora allata are necessary for the function of the accessory glands that produce this secretion. Complete digestion is effected in forms like *Melolontha*. Males secrete a structure called sphragis in butterflies, which forms a plug into which the spermatophore is pressed in at mating: the sphragis shrinks and gets lost while the sperms are released. In odonates, during flight, the male transfers the spermatophore into a sac on his abdominal segment and the female bends her abdomen and picks up the spermatophore with her genitalia. There is no intromission of the rudimentary penis in this group. Direct transfer of sperm occurs in Hemiptera, Neuroptera, Hymenoptera, Coleoptera and Diptera. In these groups intromittent organ holds the genital opening in position for sperm discharge without wastage. In some mosquitoes, like *Anopheles longipalpis*, a mating plug closes the genital pore to prevent sperm loss. In *Apis* sperms are forced into the bursa copulatrix and the male genital end (bulbus) is torn off by the queen.

In Cimicidae and Strepsiptera insemination occurs through the skin. In *Cimex* female in the fourth abdominal sternite is the organ of Ribaga or spermalege into which sperms are injected. From here the sperms migrate into the haemocoele, then to the oviduct and come to the sperm sac or conceptaculum seminis. They then move into the ovarioles and fertilisation occurs there. Injection of spermatozoa into haemocoele will not result in migration, but if semen is injected sperms migrate. It is claimed that corpora allata are activated by sperms leading on to the maturation of eggs. Many sperms are phagocytosed in the heamocoele and perhaps facilitates nutrition also. Gradations of spermalege organisation are met with in different groups of Cimicidae.

Mature female Strepsiptera live within the host protruding only her cephalothoracic tip. In *Stylops* the free living male copulates with prominence and injects sperms into the haemocoele.

Drosophila species show secretion of a fluid into the vagina by mated females, often described as a mating reaction. A stronger reaction is shown by hybrids mating with nonhybrid females. The significance of this reaction is not known. In many female insects, a postmating vigour is seen when physiological activities get modified or accelerated. The corpora allata become active, and there will be a concomitant increase in number of eggs produced in the follicle.

Oviposition

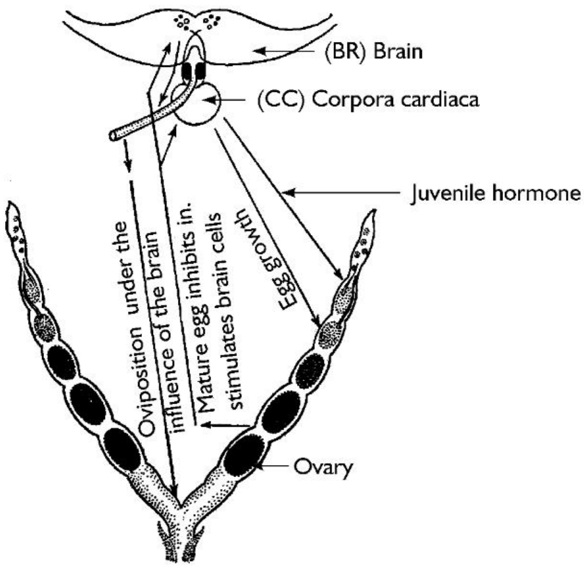
Some insects like phasmids lay the fertilised eggs at random and without any specific oviposition behaviour. But in the vast majority of insects, characteristic oviposition habits exist as a behaviour pattern to ensure suitable protection to the eggs and adequate food supply at least for the initial stages of development. Many Hemiptera and Lepidoptera oviposit on the larval food plant, generally on the unexposed side of leaves. Eggs are laid singly or in groups, and may be exposed or covered with either secretion or hairs. In *Chrysopa* the eggs are with stalks formed of secreted material which hardens on exposure to air. Eggs are laid in the soil by asilid flies and the crickets, on dung by the dung beetles or on carrion by the fleshflies or in deep burrows by the acridids. Specific sites will be chosen for laying like in cuts on plants as in tettigonids, or among flowers or leaf edges as in thrips. Parasitoids choose hosts for laying eggs on to the surface or into the body as in several Hymenoptera; an extreme case is seen in *Rhyssa* which parasitises the larval *Sirex* which lives in wood, and the ovipositor of the parasite is used as a probe to locate the host for depositing eggs. Regions frequented by hosts are also used as sites of oviposition, as in meloids. The human warble fly *Dermatobia* oviposits on mosquitoes which will take the eggs to the host, which is an example of phoresy. Eggs laid into water will be like rafts as in mosquitoes or within gelatinous envelope as in mayflies. Floating vegetation is selected for laying eggs as in *Nepa*. Egg cases which are carried about temporarily lodge eggs in cockroaches while in mantids the egg cases are laid on branches of trees. Egg pods laid in soil are employed in acridids. Egg cases of variable pattern are seen–attached ones in tortoise beetles, with air spaces as in *Coplosoma*, and mast-bearing silken case as in *Hydrophilus* are some examples.

The choice of a suitable site by a female for laying eggs has been attributed to perception of specific stimuli from sources of suitable food. This has especially been the case in highly specialised forms like gall making insects, fungivorous forms and predators. Ability to select sites with maximum suitable conditions has also been seen, as in mosquitoes selecting water bodies with less than 0.5 per cent sodium chloride and in *Lucilia* choosing artificial sites with ammonium carbonate, indole and sulphydryl mixtures.

Occasionally caring for the eggs is exhibited by the parent. The well-known examples are the forms which construct brood nests as in solitary wasps (*Eumenes*), bees (*Megachile*), and dung beetle (*Heliocopris*) where the parent cares for the young to some extent. Social insects differ from these because if at all attention is given, it will be to the first batch of eggs laid by the mother. Direct maternal protection is exhibited in some, for example bugs like

Chrysocoris guarding the cluster of eggs, egg containing silken cocoon carried under the belly in *Spercheus*, guarding eggs in subterranean nests by *Gryllotalpa*, and the nymphs being carried about on the mother's back in *Panchlora.* Male insects also show a type of parental care, but only rarely as in *Sphaerodema* and *Belostoma*, eggs being forced on to the dorsum of the insect by the laying female. A type of brood parasitism also is exhibited by a few forms, as in chrysidid wasps utilising the provision brood of bees.

Mating has been discovered to have a stimulatory influence on egg deposition. Numerous examples have been cited in literature, and it has even been suggested that an ovulation hormone may be present in some strains of *Aedes agypti.* A large number of insects retain eggs if the female remains unmated, as in Lepidoptera and Diptera, and delay in egg laying has been observed in unmated females of *Gomphocerus* and *Cochliomyia.* Oviposition is controlled by the last abdominal ganglion and its removal will inhibit or at least disturb egg laying. It is possible that other neural centres are also involved in the act, since it has been illustrated that the removal of the head induces laying of eggs in Mantis, *Plodia, Culex* and *Anopheles.* Neural control is only a partial explanation because endocrine influences also are present as elucidated in *Drosophila.* Oviposition is stimulated by injection of blood of females or males in *Bombyx.* In vitro studies on *Carausius* oviducts showed that brain extracts will increase the contractile activity. In *Iphita* (Fig. 26.6) the fully ripened eggs liberate a principle into the blood, which causes the brain cells to secrete a hormone stimu-



▲ **Fig. 26.6** *Neuroendocrine control of reproduction of the female Iphita* lating the motility of oviducts and egg laying (Nayar, 1958).[1] In *Musca* a ecstatic hormone has been described, which can inhibit the release of the juvenile hormone terminating egg growth at a specific stage (Adams, 1970).[2]

Behavioural changes are shown by the females with mature ova. Avoidance of males, use of legs and antennae to probe for egg laying sites, exserted genitalia, increased salivation, and partly extended proboscis, besides gradual advances to crevices or dark areas, form a well-defined pattern in *Iphita*. *Pieris* females are attracted to green, blue and blue-green colours at laying time. Rhythms infulence egg laying patterns. Egg laying occurs at night in *Eupterote*, during twilight in *Catopsilia*, and during definite periods of the day in *Clysia*, or throughout the day as in mudpot wasps.

Heterogony is the alternation of bisexual and parthenogenetic modes of reproduction. Aphids, cynipids and gall midges show this phenomenon. Extensive studies have been made on aphids. A simple case occurs in *Acanthochermes* where in April the zygote gives rise to a fundatrix. This will lay eggs which develop as parthenotes into the sexuales, either female or male. Females produce eggs in May which are fertilised and from these will emerge fundatrices in the next April. This is a simple case of alternation of bisexual and parthenogenetic generations. Complexities in this method arise in other aphids, often associated with additional food plants and formation of various types of individuals. For example, in *Sacciphantes* the fundatrix living on spruce produces the migrant individuals (alata migrans) migrating to larch; the migrant individuals produces the over-wintering virgins (hiemosistens); generations of these are formed (progedientes) and later sex-producing exsulis sexuparae arise, which migrate back to spruce and give rise to sexuales. These later gives rise to the fundatrix.

The physiological control mechanisms in heterogony are not well understood. One notable feature of the virgin generations is polymorphism, the aphids appearing with wings or apterous. Crowding has been seen to be a factor favouring development of winged forms. Additionally tactile stimuli and food may also be determining factors. Photoperiod and temperature also have decisive roles.

Fecundity

In insects fecundity is assessed by the production of viable eggs. It is dependant on various external and internal factors, and fecundity declines is met with as the insect ages. Based

[1] Nayar, K.K. 1958. *Proc. Indian Acad. Sci.,* **B 47**: 233–51.

[2] Adams, T.S. 1970. *J. Insect. Physiol.,* **16**: 368–381.

on observations in the laboratory, the average number of eggs laid by a female is variable, 12 in *Melophagus*, to as high as 120,000 in *Apis*. Generally the number of eggs vary from about 100 to 300, in the different species known. When there are more ovarioles, the number of eggs is more, but where ovarioles are few as in Coprinae with a single ovariole, there is parental care of the few eggs that will be laid.

External factors like the quality and quantity of food decides fecundity. Larval food will be contributory in the forms which do not feed like the adults. In adults where feeding is possible, food and vitamins play a significant but variable role in deciding fecundity. Lipid and sterol requirements for reproduction have been analysed to some extent. In *Drosophila* cholestrol is essential for reproduction and in *Musca* though the number of eggs produced remain more or less the same, only one-fifth of them hatch. In the rabbit flea *Spilopsyllus*, the eggs are produced only during the last 10 days of the pregnancy of the host, while those fed on post-partum females or males, failed to lay eggs indicating that an egg-maturing factor is inhibited in the flea by the host. Spraying with progesterone regresses ovaries of the flea and hydrocortisone spray stimulates egg growth. The male requires a blood meal from pregnant doe to become mature and mate effectively. Synthetic JH applied externally also produces similar effects (Rothschild* *et al.*, 1970). Tsetse fly sucking blood from pregnant goats showed increase in its fecundity.

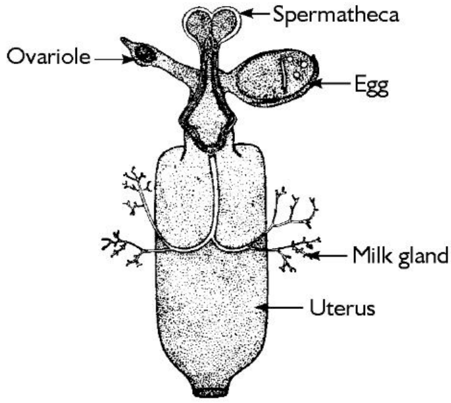
Adults which do not feed are able to reproduce showing high rates of fecundity; mayflies are an example. This is an instance of autogeny, as it is reproduction without imbibing protein food. Here, the real biology of reproduction involved is not clear.

Environmental factors affect fecundity. Temperature, humidity, photoperiodic influences, crowding, suitability of hosts for parasites, cessation of activity based on environmental conditions, etc. are important factors to be taken into account. The genetic makeup reacting to the environmental conditions also have to be taken into account; reduced fecundity has been observed in inbreeding strains of *Oncopeltus*.

Viviparity

In some insects the female retains the fertilised eggs which continue to develop partly or completely. This is viviparity. Different types of viviparity have been described. When embryonic development occurs within the female but without nutritive supply from the mother, it is called ovoviviparity. This condition is seen in some blattids, thrips and *Chrysomela*. Here the embryos are dropped after part development as larvae as in the gall midge *Thurauia* or after complete development as in *Blaberus*. In *Glossina* (Fig. 26.7) and *Hippobosca*, specialised structures are developed from the mother to nourish the growing embryos, this being described as adenotrophic viviparity. In gall midges and Strepsiptera the embryos lie in the haemocoel of the mother and nourishment passes through the membrane of the egg. This is haemocoelic viviparity. Placenta-like structures are developed in *Macrosiphum, Hemimerus*, *Diploptera* and *Hesperoctenes*, either from the mother, or from the embryo or from both, this is distinguished as pseudoplacental viviparity.

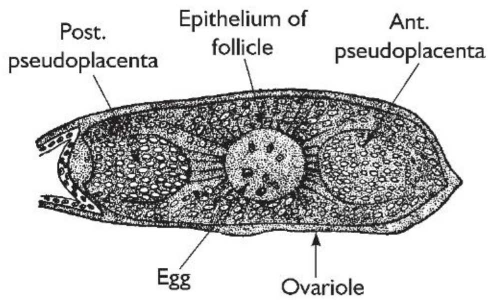
Among the different types, ovoviviparity arises sporadically in several orders of insects. Here the size of the egg is usually large to contain more food. The number of eggs produced in all viviparous forms will be reduced.



▲ **Fig. 26.7** *Female Glossina reproductive system (R.F. Chapman, 1969)*

In adenotrophes, fully-developed egg with chorion moves into a specialised uterus. The emerging larva then lives in the uterus and the branched maternal glands provide nutritive secretion. The larva ultimately emerges out of the mother. The non-feeding pupal stage is external. In *Glossina* only two ovarioles are present and each ovariole releases an egg alternately. Embryo develops rapidly, and when it enters the uterus, the chorion is ruptured by a special structure on the uterine wall (choriothete). The maternal glands secrete a milk which is sucked up by the larva. The larval mouth is applied to a nipple from the milk gland. Specialised respiratory structures are developed as instars pass, air being sucked in through the maternal genital pore. During development, hindgut remains as an occluded portion to receive the waste.

In haemocoelous viviparity, oviducts are wanting, and mature eggs migrate into the haemocoele. In Strepsiptera fertilisation occurs within the haemocoele. The nutriment is transferred directly from the blood to the embryonic haemocoele. The larvae emerges from the parent by eating through the tissues in cecidomyiids or through the insemination canals in Strepsiptera. In pseudoplacental viviparity as shown in *Hemimerus* (Fig. 26.8) the egg is without yolk or chorion. A single follicular nurse cell divides into masses on either side of the egg to form maternal false

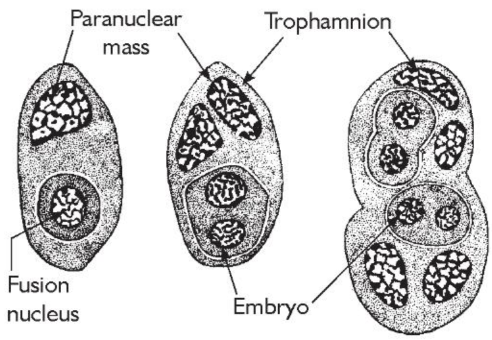


▲ **Fig. 26.8** *Hemimerus developing embryo in early stage (ibid)* placentae. As development proceeds, feeding cells or trophocytes emerge from the embryo contacting the anterior pseudoplacenta. Then the embryo grows around it with the amnion forming a foetal pseudoplacenta.

In *Diploptera*, pleuropodia are believed to help in absorption of nutriments.

Polyembryony

In some insects an egg instead of giving rise to a single larva may produce two or more embryos by a process known as polyembryony. It is a regular feature of reproduction in some endoparasitic forms as in *Platygaster*, several ichneumonids, some cecidomyiids, etc. In *Platygaster* the maturing oocyte produces two polar nucleus or a paranucleus to form a trophamnion, the rest contains the zygote nucleus (Fig. 26.9). The embryo develops from the zygote nucleus, by cleaving into two. The whole mass then divides into two and the two grow into two embryos. The trophamnion helps to pass nutriment through it.



▲ **Fig. 26.9** *Platygaster: Stages in embryonic development (ibid)*

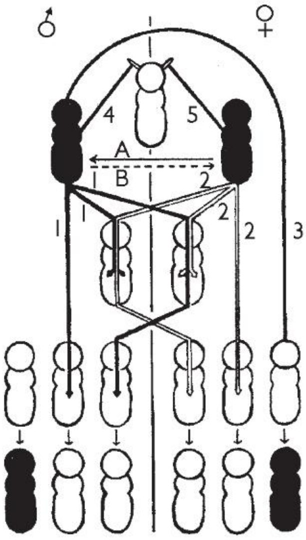
Paedogenesis

It is the larval reproduction by parthenogensis. In *Miastor* the larva gives birth to other larvae, when there is abundant or scanty food. The young eat through the larval mother and adults arise from these if conditions are fairly satisfactory. In the midge *Henria* the pupae paedogenetically reproduce. Some of the emerging larvae become normal adults, but others form a hemipupa with only vestiges of wings and legs. Hemipupae can withstand adverse conditions of the environment for up to 18 months.

Inhibition of Reproduction in Social Insects

In social insects there is an inhibition of reproductive abilities; the workers of a honeybee colony are sterile females, and in ants and whiteants the various subcastes comprise of sterile females and males. Two major theories have been presented to explain the determination of the castes in insect societies—trophogenic and genetic. In more recent years, pheromonal control has been found to be responsible to a large extent in the determination of subcastes. Secretion from the mandibular glands of the queens inhibits queen rearing and ovaries of worker bees. It is called the queen substance and is 9-oxo-*trans*-2-decenoic acid. Subsequently, another volatile substance has been found acting through smell to inhibit functioning of the ovary of the workers—this is designated now as pheromone II. The mode of action of these pheromones is not clear.

In the termite *Kalotermes* only a few sexually-reproducing individuals occur, there are additional supplementary reproductives which become sexually mature only on removal or migration of sexuals. It has been found that the 'royal pair' inhibits reproductive abilities of other members of the colony. Normally a queen (Fig. 26.10) produces a substance which inhibits the development of female pseudergates. Absence of this substance will promote production of supplementary reproductives. Likewise, the male produces a pheromone inhibiting development of male pseudergates and the production of the male pheromone is stimulated by the queen. To a lesser extent the king also influences the queen's production of pheromone. The inhibitory substances are produced from the head or the thorax and pass through the gut, and the pseudergates imbibe them by anal licking and pass from individual to individual during mutual feeding and it is suggested that a female feeder absorbs the queen substance and passes on unchanged the male substance and *vice versa* by the male. Additionally, the king produces a substance which stimulates female production in the absence of the queen substance. However, such a potent male producer from the queen has not been detected. Excess males or excess females get eliminated by substances produced by the king and the queen respectively. Pheromones of these category are olfactorily acting and emanate from the skin. A fixed number of soldiers are formed and this number remains unchanged throughout the life of the colony rising up only in proportion to the number of members of the colony as it increases, and soldier production is also controlled by pheromones.



▲ **Fig. 26.10** *Kalotermes, Pheromonal control of reproductives. The numerals indicate the pheromones (1 to 5). A and B are pheromones of an unknown nature (courtesy: M. Lüscher)*

In ants also queen substance is present at least in forms like *Formica* where queen inhibits queen production. But ovarian inhibition is not strictly comparable to the other social insects studied, and the pheromonal mechanisms in the life of ants requires more intensive study.

Section Three

Ecology

◆ Chapter 27

Insect Biodiversity

Biological diversity encompasses the vast number of species of plants, animals and microorganisms such as bacteria and fungi. These may occur as individuals, populations, communities or as an ecosystem, thus forming a part of the biosphere. Increased human interference has threatened the stability of many ecosystems and habitats have been destroyed or changed to meet the needs of our ever increasing population. In terms of biodiversity, loss of both species and gene reservoirs are significant and pose a threat to human welfare. Biological diversity is essential whether it is for agriculture and forestry systems, or for the protection of over all environmental quality or for the intrinsic worth of all species. Arthropods are the most diverse making up approximately 90% of all species. Crop and both natural and managed forest ecosystems have abundant arthropod species which contribute a great amount of biomass and a large number of species to these ecosystems.

India is considered as one of the most biologically diverse countries in the world, particularly because of the large number of ecosystems which nurture an extraordinary number of animal and plant species. There are an estimated 68,370 species of animals of which 60,000 are insects. There are another 4,000 species of plants. While this is the Indian scene, from the global view point, of the 1.4–1.5 million species, 75,000 to 100,000 species are insects, 41,000 vertebrates and 250,000 species of plants. Tropical forests are reduced to half its size through human intervention. It has to be emphasized that living organisms in these heterogeneous habitats generate an enormous amount of genetic diversity needed for rapid speciation. In addition to insects, the large number of species of wild legumes, wild rice, wild citrus and hundreds of medicinal plants are store houses of genetic diversity in tropical forests.

An idea of insect diversity and endemic species in India as of 1994 is provided in Table 27.1. Endemic species or species confined to particular geographical areas are very typical of insects and an understanding of the degree of endemism becomes important in studies of insect biodiversity. Endemism is very high both at the genetic and specific levels. The question of the need for sustaining several thousands of species is an arguable one, and we have scanty information on the role of individuals in particular ecosystems. It is in

Table 27.1 Insect Diversity and Endemism in Insecta of India

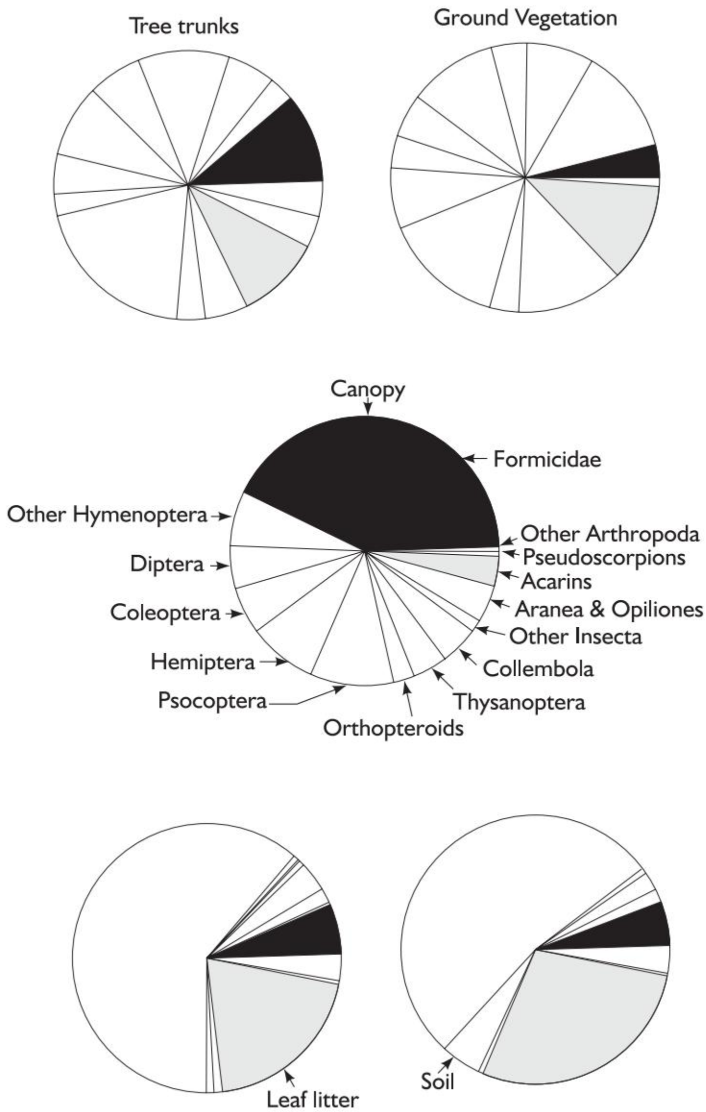
Group	*India*	*World*	*% in India*	*Endemic No.*	*species %*
Insecta	51,011	839,052	6.08	16,214	31.78
Thysanura	30	1,250	2.40	23	77.0
Diplura	16	355	4.50	12	75.0
Protura	20	260	7.69	17	85.0
Collembolla	205	5,000	4.10	92	44.87
Ephemeroptera	94	2,146	4.38	72	76.59
Odonata	494	5,500	8.98	115	23.27
Plecoptera	113	2,100	5.38	66	58.40
Orthoptera	900	4,491	20.04	330	37.0
Phasmida	60	2,500	2.40	37	61.66
Dermaptera	320	1,800	17.77	144	45.0
Embioptera	33	200	16.50	14	42.42
Blattaria	156	4,200	3.71	62	39.74
Mantodea	162	2,000	8.10	88	54.0
Isoptera	310	2,000	15.50	145	47.0
Psocoptera	85	2,500	3.40	9	10.58
Mallophaga	400	3000	13.30	16	4.0
Hemiptera	5216	80,000	6.52	2421	46.0
Thysanoptera	702	6,000	11.70	493	70.0
Neuroptera	315	5,000	6.30	256	81.26
Coleoptera	15,289	3,50,000	4.39	5198	34.0
Strepsiptera	11	300	3.66	8	72.0
Mecoptera	15	350	4.28	2	13.0
Siphonaptera	52	2,000	2.60	15	28.84
Diptera	6,093	96,600	6.31	2135	35.0
Lepidoptera	15,000	142,500	10.52	1500	10.0
Trichoptera	812	7,000	11.60	70	8.62
Hymenoptera	4,264	100,000	4.26	2920	68.0

Source: A.K. Ghosh, Biodiversity and Entomology. Ninth Dr. C.P. Alexander Memorial Lecture, Department of Zoology, University of Delhi, New Delhi, 1998.

this context that an understanding of food webs becomes important, so as to assess the significance of the concerned species. Eliminate one species and another increases in number; but eliminate a great many species and the local ecosystem starts to decay. The restoration power of the fauna and flora as a whole depends on the existence of enough species to maintain a balance. By virtue of their effective role in the maintenance of ecological balance at all levels, tropical forests have played a major role in economic development. It has to be emphasised that these highly diverse natural ecosystems support a wealth of species which serve to maintain hydrological cycles, recycling of essential nutrients, soil formation, while their litter provides important ecological services.

Thus biological diversity exists at three levels, the ecological, taxonomic and genetic. Taxonomic diversity is critical because taxa are units that contain genetic diversity which in turn contribute to ecological diversity. Included, therefore, in biodiversity are such aspects as phenotypic plasticity, genetic variation within a population, species richness and diversity—functional diversity, community and landscape diversity. Landscapes diversity refers to the significant changes in biodiversity due to habitat loss, fragmentation and modification. Some species are more important to the ecosystem than others as indicators of ecological processes or as key store species that influence community structure essential for ecosystem stability and diversity. Besides there are species guilds which are taxonomically different but functionally identical. Such species guilds abound in the forest canopy, beneath it and in the leaf litter. Guild composition has been studied in tropical areas like the forests of Borneo.

In terms of feeding habits or guilds, there are the parasitoids, ants, scavengers, epiphyte grazers, insect predators, etc. Even within species restricted to a single tree type factors such as age of the tree, height, canopy depth, trunk girth, all have a bearing on faunal composition. A comparative idea of the faunal components of tree trunks, ground vegetation, canopy, leaf litter and soil is depicted in Fig. 27.1. From a single tree in the Amazon, 43 species of ants were identified, not to mention 1,200 species of butterflies, while beetles contributed to 40% of all canopy insects. Deforestation results in unimaginable loss of biodiversity and these millions of species are so highly specialised that they are quickly driven to extinction by disturbance of their habitats. An understanding of patterns of species diversity, abundance of litter insect composition in natural, and disturbed ecosystem is important. The bewildering diversity of insects and their structural complexity in natural ecosystems are important since insect species abundance, species richness and functional dynamics are closely linked to the stability of ecosystem.

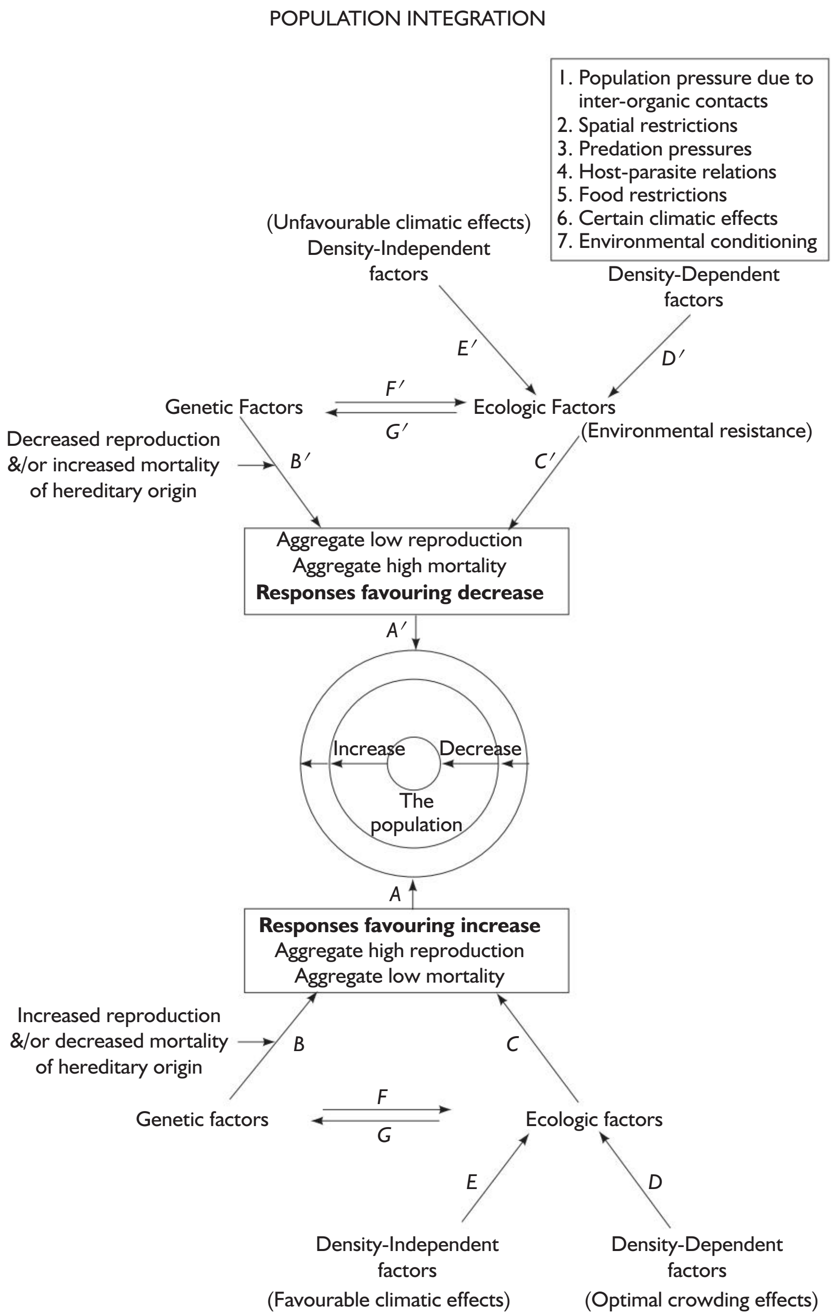


▲ **Fig. 27.1** *Pic. chart illustrating faunal components of tree trunks, ground vegetation, canopy, leaf litter and soil*

◆ Chapter 28

The Environment of Insects

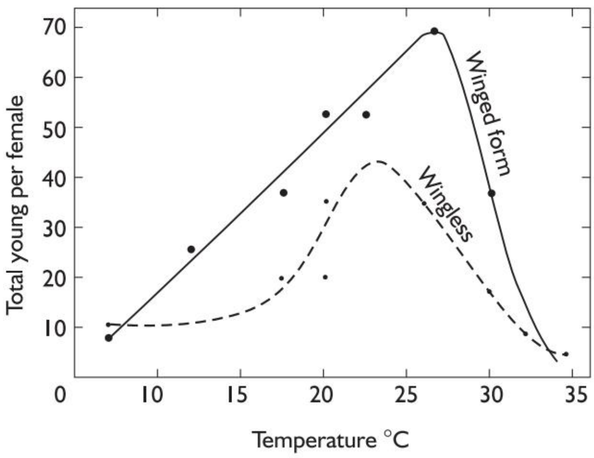
The activities of insects are governed by several factors, both intrinsic and extrinsic. Ecological studies aim at a proper evaluation of the immediate environment which restricts the insects to their particular living places. It is common to interpret the relationships between the insects and their environment from the view point of the individual species (autecology) and that of the community, which involves a study of the inter-relationship of population of different species inhabiting a given area (synecology). There has been a growing tendency to lay special emphasis on population dynamics, dealing with the gross effects of the action of the external environment on the population, determining its abundance (including mortality and natality or birth rate) and their distribution. The essential components of the environment which often determine the survival of an insect species and influence their behaviour, development and fecundity are temperature, humidity and light (i.e. weather), food, other animals, disease producers and the habitat (Fig. 28.1). The habitats have usually been distinguished into the macro- and microhabitats, the latter including soil, litter, carcass and dung, barks of trees, tree trunks, fallen logs, crevices of rocks etc. These microhabitats provide excellent instances for a study of ecological succession. Further, studies on energy flow in ecosystems or energy transformation occurring within ecosystems ecological energetics—based on the principles of thermodynamics have become the modern trend in ecological studies. Such studies naturally involve transfer of energy through a series of organisms (food chains). Only the general aspects of insect ecology dealing with the immediate effects of the environment on insects are attempted here as details of every aspect of ecology would be beyond the scope of this book and can be had from any standard book on ecology.



▲ **Fig. 28.1** *Schematic representation of interplay of factors that affect insect populations*

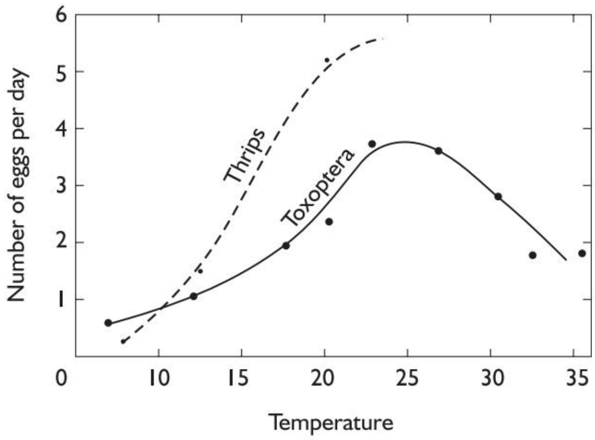
Temperature

The various activities of insects are often adversely affected by extremes of temperature and the optimum temperature range varies with different species and even sexes. In ecological studies it is usual to speak of optimum temperature when there is maximum development or survival; the zone of effective temperature is the range of temperature wherein they are active; threshold of development is the temperature at which there is minimum activity; beyond the maximum and minimum effective temperatures are the fatal-high and fatal-low temperatures; very few insects are endowed with the capacity to live in hot springs at temperatures of 60° to 65° C and the firebrat *Thermobia domestica* lives at 25° to 45° C. At the other extreme, some Collembola, beetles and butterflies have been recorded in the snowclad Himalyas. Besides these few instances, the lives of the majority of insects are influenced by differences in temperature levels and from a generalised point of view it may be said that temperature exerts a profound influence on fecundity and the rate of egg production, rate or speed of development, and rate of migration or dispersal.



▲ **Fig. 28.2** *Graph showing the influence of temperature on fecundity of the aphid Toxoptera, (Andrewartha and Birch, 'The Distribution and Abundance of Animals'. University of Chicago Press)*

The optimum temperature for oviposition varies with species and in general, the maximum rate for egg production happens to be almost near the upper limits for reproduction. The aphid (Fig. 28.2) *Toxoptera graminum* has a wide temperature range preference for oviposition, between 5° and 35° C; the oviposition of the bed bug *Cimex* is inhibited at 8° to 10° C, while *Pediculus* does not oviposit below 25° C. In *Sitophilus oryzae* the number of eggs laid reaches a maximum at 26° C for the thinner population and at 29° C for the more dense ones and only very few eggs are produced at temperatures above and below these. *Thrips imaginis* inhabiting roses in Australia, lay very few eggs at 8° C, but large numbers are laid between 13° to 23° C, (Fig. 28.3). It may be safely said that fluctuations do occur in the oviposition or reproductive rates, particularly when we take into account the variety of habitats in which the insects live. In general between temperatures of 0° and 25° C, most insect populations show a marked increase in the rate of reproduction or oviposition. The oviposition rate in *Anaphothrips sudanensis* for the months of January and February at temperature of 25° to 28° C is lower, and in July-August at 33° to 36° C is higher. Adults show a shorter life span during July-August combined with a higher oviposition rate, perhaps as an adaptation.



▲ **Fig. 28.3** *Graph indicating relationship between temperature and speed of egg production for Thrips and Toxoptera (ibid)*

As in the case of oviposition rate, the rate or speed of development is also influenced by narrow range of temperature. The lower and upper limits of temperature required for development from the egg to the adult in *Sitophilus oryzae* are 15° and 34° C, in *Rhyzopertha dominica* 18° and 30° C, in *Ptinus* 5° and 28° C, and in the collembolan *Sminthurus viridis* being 7° and 27° C. It is also to be emphasised that different stages in the life cycle of insects have been found to react differently to weather factors; extreme temperatures have been known to induce rapid development. Though the rate of development is usually greatest at a particular temperature, mortality rates increase near the lower and upper critical limits. Laboratory conditions have their own limitations because in many cases in spite of optimum conditions provided, very few become adults even though the eggs successfully hatch and the larval development progresses well. In many holometabolous insects, the different stages of the life cycle live in different habitats and at different ranges of temperature. It would be of interest to observe that *Sitophilus oryzae* which lives all through the year in the same wheat, completes its life cycle in 10.4 days at 18.2° C, while at 29.1° C it takes only 3.6 days. Further, in all cases it has been observed that the basic relationship between temperature and rate of development is not linear but curvilinear.

A good example of the influence of temperature on the rate of migration or dispersal is provided by the locusts, in particular *Schistocerca gregaria*, where migration of swarms have been known to occur at temperatures of 17° to 20° C. The presence of upward thermal currents near the ground surface has been known to influence the beginning of migration and in the absence of these currents, migration commences only at relatively high temperatures of 22° to 23° C, when they are more active. There appears to be a correlation between the maximum temperature of the previous day and the temperature at which migration begins, sence this is considered to be of importance in the appearance of upward thermal currents. Seasonal and daily trends in fluctuation of *Thrips imaginis* on rose has been studied for a period of 14 years. The studies also showed that the independent influence of temperature was highly significant and that on an average the number of thrips in the flowers on any one day increased by 25 per cent for every increase of 5° C.

At exposure durations of about half an hour, the upper lethal limits of heat and cold hardiness in insects (the tolerance to extreme heat and cold), appear to be between 40 and 50° C. In natural environments, the process of temperature acclimation plays an important role in helping to withstand high temperatures. This is due to the gradual temperature rise over the earlier months. The mortality threshold of the insects would be raised both during these months as well as during the day time, when the critical temperature hours are preceded by sublethal temperatures, making again physiological acclimation possible. In the laboratory, insects have been preconditioned by exposing them for a short time to sublethal temperatures and as a result the lethal temperatures could be raised and an example of this is seen in *Drosophila pseudobscura* which was preconditioned for two hours at 36° C. Studies on cold resistance have shown that many species die when exposed to temperature near freezing point and high rates of mortalities occurred as in the case of honeybees, which were exposed for 2 days at 5° and 10° C. An interesting aspect of cold hardiness relates to the ability of the insects to survive cold untill their body fluids freeze. It is also well known that insects undergoing diapause in response to severe winter conditions, have greater cold hardiness. Other insects have been known to have super cooling limits of –30 and–35° C. They survive at these temperatures and available information shows the presence of high concentration of glycerol in all their tissues.

Light

Light plays an important role in the growth, development and survival of insects. It is a vital factor in relation to behaviour and as a stimulus leading to the production of diverse morphological and physiological variants. It is needless to mention that light is the prime source of energy in all organisms. In insects, the eyes and ocelli are the chief receptors of light.

In many insects oviposition is stimulated by exposure to light or darkness. The codling moth, the cotton boll worm *Earias* and *Amsacta* are of interest in view of their ovipositing in darkness. They could be induced to lay eggs or stop oviposition by exposing them to darkness and light respectively. On the contrary some fruitflies (*Bactrocera* spp.) have been known to lay eggs only in light. Light also has some influence on growth as seen by the example of *Tenebrio* larvae which live in the dark. When the third instar larvae of the silkworm *Bombyx mori* are kept in the dark, they develop into the fourth instar in five days, while in light, they develop in 3.5 days.

Emphasis has been laid on the influence of the day length or photoperiod and annual cycles of photoperiod on the life cycles of insects. Photoperiod refers to the number of hours of light and darkness occurring during each 24-hour day, the day light portion being termed the photophase and the dark period, the scotophase. The main function of the photoperiod appears to be to provide environmental information in the form of signals to which insects respond. The influence of light periods on insect activities has been demonstrated in *Periplaneta americana.* Many motor activity patterns such as locomotion, feeding activities, adult emergence, mating and oviposition are influenced by photoperiod. Most insects and other organs have a circadian rhythm.

That photoperiod exerts an influence on the emergence rhythms of adult *Drosophila* is seen from the fact that in cultures kept in continuous darkness, emergence was at a random and did not occur for four days, while in those kept in a regular photoperiod, emergence of adults has been maximum after the onset of light each day.

The influence or effect of photoperiod on the seasonal form of insects, in particular butterflies, is evident in that the growth processes develop in one direction, if the days are long and in another direction during short days. Experimentally, if caterpillars are grown in the laboratory and exposed to light for 12 hours per day, the butterflies coming out will be light-coloured, while dark-coloured forms will result when exposed to light periods of more than 16 hr. This variation in the light or dark schedule has also formed the basis of an explanation for the production of sexual and parthenogenetic forms in aphids, where a change from the non-sexual to sexual reproduction has been found to occur as a result of short day length in late summer and early autumn. Reproduction is parthenogenetic and viviparous during longer day lenghts and oviparous and sexual during short day lengths. Under laboratory conditions it has also been shown that the aphid *Megoura viciae* reproduces sexually under photoperiods of less than 14.5 hr of light per day, while under photoperiods of more than 15 hr, nonsexual forms are produced.

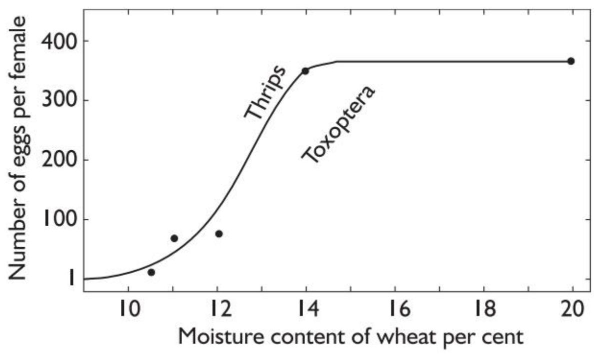
Humidity

Insects, like other terrestrial animals have to maintain the water content of their bodies at a fairly constant level, and they die when the water content falls or unduly increases. This indicates the need for a tolerable zone of moisture between the 'lethal wetness' and 'lethal dryness'. Lessening of the water content usually leads to retardation of development and lowering of metabolic rate. The ability to withstand water reduction varies with different insects, and depends on the water content which varies from 50 to 90 per cent of the body weight. It is less (46 to 47 per cent) in thick skinned insects like *Sitophilus oryzae* and high in thin-skinned insects like lepidopteran larvae where the water content may be as high as 90 to 92 per cent.

Water is obtained from their food in particular in blood- and sap-sucking insects, while others drink water as in flies, cockroaches, etc. Some absorb water through their cuticle and in particular those which live in the soil have to absorb water during development. Yet others retain water which is lost as a by-product of respiration during the oxidation of fats and carbohydrates within their tissues. When necessary, they can increase the quantities of water by oxidising the excess quantities of fats and carbohydrates. This is particularly so in insects living in a dry atmosphere and water so made available is called the metabolic water and the rate of production of this is determined by the humidity of the atmosphere in which the insects live. The ventral tube in some Collembola and the eversible vesicles of Thysanura also appear to play a role in the absorption of water. The eggs of all grasshoppers and locusts have fine adaptations for water absorption through the development of a group of very large cells—the hydropyle cells. Beneath the hydropyle is a specialized part of the cuticle through which water enters and leaves the eggs. Many insects like the gryllids and some Hemiptera have enlarged serosal cells near the micropylar region which can absorb water during development. Water conservation in eggs may also be effected by the presence of a waxy layer in the cuticle to prevent desiccation.

Loss of water takes place mostly by evaporation through the cuticle, by excretion, and through faecal matter. Water loss from body surface takes place through the cuticle and the spiracles. In some insects like grasshoppers the evaporation through the spiracles has been found to be 60 to 70 per cent. Spiracular control in general is greatly influenced by humidity, the spiracles being more closed in dry air than in relatively higher humidity levels.

In order to ensure survival, there must always be a proper water balance, which when upset leads to desiccation. Some insects require a saturated atmosphere and without it water loss takes place, while others are adapted to dry conditions and can even withstand starvation for several days, because of adaptations to retain water. Such insects when exposed to air with a relative humidity of about 70 per cent at temperatures of 30° to 37° C, are unable to cope up with the new situation, because at these temperatures their metabolic rate is high, so that there is an increase in water content in the body. There appears to be therefore a good correlation between temperature and humidity. In *Sitophilus oryzae* and *Rhyzopertha dominica* this interaction is very evident (Fig. 28.4). They lay eggs within an optimum range of temperature and do not oviposit at any temperature when the moisture content of the wheat is low, i.e. 10 per cent in the case of *Sitophilus oryzae* and 9 per cent in *Rhizopertha dominica*. Fecundity is greater at a moisture gradient of 12 to 20 per cent. A rise in temperature always increases evaporation. In *Blatta orientalis* for instance water is lost in atmospheres of different relative humidities and at different temperatures.



▲ **Fig. 28.4** *Total eggs laid by Sitophilus oryzae at 29.1 °C in wheat of different moisture content (ibid)*

The behaviour of insects in a moisture gradient is shown by experiments on the flour beetles *Tribolium castaneum* and *T. confusum*. These live in their environments (flour) with 10 to 12 per cent water. When kept starved for several days in dry air [zero relative humidity (RH)] and then placed in moist air, they come to rest; but with shorter periods of starvation, the response is immediate, as in *T. castaneum*. Both *Tribolium* and *Tenebrio* larvae possess an efficient mechanism for retention of a fairly constant amount of water in their tissues, when they undergo starvation in air.

Moisture also appears to influence fecundity in some insects as seen in the case of *Locusta migratoria* which failed to produce eggs at about 40 per cent RH; at 70 per cent RH it became sexually mature and if maintained at this level, the length of life was found to be shortened. Within a zone of 40 to 80 per cent RH and at temperature of 32.2° C, the length of life depended upon the rate of sexual maturity. In dry air there was no development at all. The total number of eggs laid in the lifetime of an insect or its fecundity was greatest at optimum–70 per cent–RH in *Locusta*. Above and below this level there is a decrease in the number of eggs produced. There are, however, exceptions in that in some insects like *Sitophilus oryzae*, fecundity increases with the moisture content of wheat it is feeding on—from 34 per cent RH to a maximum at 70 per cent. Studies relating to the influence of humidity and population density in *Callosobruchus chinensis* (Utida, 1941) showed that at 76 and 52 per cent RH the total number of progeny increases with density of about 192 per vial, and then sharply declines. With regard to the reproductive rate per female, it has been high in the lowest density and decreased with crowding.

The speed of development may be retarded at high humidities as in the nymphs of *Loscusta migratoria*. In insects occurring in dry places, like *Cimex, Thermobia, Bruchus* and the clothes moth *Tineola*, the speed of development is independent of humidity.

◆ Chapter 29

Dynamics of Insect Populations

The role of quantitative studies dealing with the interaction of environment and populations, forms an essential aspect of ecological investigations. Populations are usually defined as a group of interbreeding individuals or an assemblage of individuals of a particular species occurring in a particular place. The environment of a particular population naturally includes the abiotic or physical or climatic factors and the biotic factors including other populations of animals and plants. Natural populations have well-defined characteristics which include their density or degree of crowding in a unit of space, birth rate or natality or population increase factor, mortality or death rate or population decline factor, genetic make-up, dispersion or distribution, and space range or territoriality. Typically, therefore, every population has a growth rate, or growth form which naturally results from the birth rate, mortality rate and dispersion of individuals (Fig. 29.1).

The density or degree of crowding along with the nature of their assemblage–whether uniform, random or clumped–is vital to an understanding of the interactions between the individuals forming a population. Several views exist seeking to explain the abundance and distribution of insects in natural populations. Howard and Fiske (1911) used the terms 'catastrophic and facultative' factors respectively for climatic factors and natural enemies controlling a population. Smith (1935) introduced the terms density-independent and density-dependent factors for the catastrophic and facultative factors respectively of Howard and Fiske. The term 'density-independent' mortality factors has not been widely used by most ecologists (though it has been used in a specific, restricted sense), since it has been found that no particular environmental factor constantly keeps a proportion of any population down, or these factors acting alone cannot maintain an average density or balance over long periods of time. In other words it should not be considered that high mortality rates are always caused by environmental factors alone, but that fluctuations in birth and death rates may come about both by genetic and environmental effects. The term density-dependent factors has come to be used widely as primarily responsible for the control of populations, the chief factors being intraspecific competition for food and space and interspecific factors involving the action of predators and parasites. Among the several current theories explaining the abundance of insects are those of Andrewartha and Birch (1954)[1] who define environment in relation to the individual. According to them populations are groups of individuals each having a different environment and that balance in populations is achieved by the favourability or unfavourability of the environment in time. They are also of the view that the density dependent factors do not take into consideration the fluctuations of populations as a result of periodic and seasonal fluctuations. Nicholson (1954)[2] prefers to use the term density governing factors instead of density-dependent factors and to describe those that hold the population in balance in their environment in spite of environmental changes. In other words populations are self-governing systems. Solomon (1949)[3] emphasises the inseparable nature of populations and the environment and that even in restricted environments there is an interaction between them in the determination of population numbers. The whole complex of populations and environment—the ecosystem—is in a stable state of existence wherein populations of individual species tend to fluctuate within limits. Milne (1957)[4] emphasised the combined action of density-independent factors like weather, imperfectly density-dependent factors like interspecific competition and perfectly density-dependent factors including intraspecific competition for food and space. Chitty (1960)[5] emphasised the genetically induced changes in individuals associated with changes in population density. Individuals in a population vary in size, structure, physiology, fecundity, behaviour, and so on and when these variations are genetically induced the action of environmental factors tend to be selective and gradually in course of time the populations will get adapted to the environmental stresses. It is this adaptation that provides a mechanism tending to maintain an equilibrium or balance between the population and the environment. Pimental[6] (1961) draws attention to mutual adaptation between innate characters of the species and those of the food plants and enemies and points out that in the course of evolution the genetic feedback mechanisms between predator and prey will tend to replace

[1] Andrewartha, H.G. and L.C. Birch. 1954. *The Distribution and Abundance of Animals*. University of Chicago Press, Chicago.

[2] Nicholson, A.J. 1954. An outline of the dynamics of animal populations, *Australian J. Zol.*, **2**: 9–65.

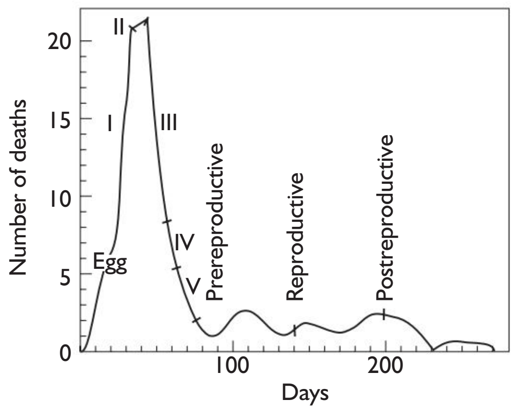
[3] Solomon, M.E. 1949. The natural control of animal populations. *J. Anim. Ecol.* **18**: 1–32.

[4] Milne, A. 1957. Theories of natural control of insect populations. *Cold Spring Habor Sym. Quant. Biol.,* **22**: 253–271.

[5] Chitty, D. 1960. Population processes in the vole and their relevance to general theory. *Canad. J. Zool.,* **38**: 99–113.

[6] Pimental, D. 1961, Animal population regulation by the genetic feed back mechanism. *Amer. Nat.* **100**: 463–65.

the density stabilizing mechanisms especially those outlined by Nicholson (1958)[1]. DeBach (1964)[2] on the basis of studies on natural control of insects emphasizes the influence of both abiotic or physical factors and biotic factors on the rate of increase of a species and the variability of environments.



▲ **Fig. 29.1** *Approximate mortality of Schistocerca gregaria during states of its life (after Bodenheimer, Alle et al., 'Principles of Animal Ecology', Saunders & Co., with the permission of the publisher)*

Reproductive potential influences natality or birth rate. The average longevity or life span of individuals in a population under ideal conditions is termed physiological longevity, while that under a given set of conditions as in experimental populations is ecological longevity. Species with a high reproductive potential have a greater death rate and the intensity of mortality could be obtained by examining the differences in size between two populations with conditions provided both for physiological and ecological longevity. The work on longevity studies relating to the locust *Schistocerca gregaria* in particular, relating to the mortality of populations over the stages of their life cycle—the egg stage, five nymphal instars, the pre-reproductive, reproductive and post-reproductive imaginal periods—is of interest (Fig. 29.1). Mortality rates are high in the first and second instars perhaps due to the susceptibility to predators, reduced mobility and rigours of post-embryonic development, among others. Mortality is the lowest during the post-reproductive period. An aspect which may be emphasised in population studies is their age distribution in relation to reproduction. Bodenheimer[3] accordingly distinguishes three ecological age—periods, of

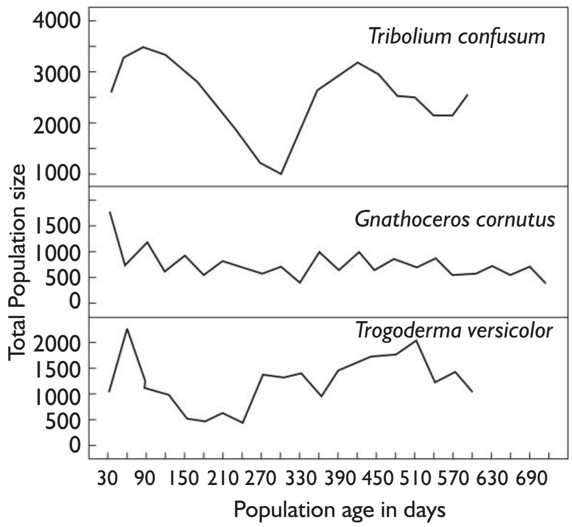
[1] Nicholson, A.J. 1958. Dynamics of Insect Populations. *Ann. Rev. Entomol.,* **3**: 107–36.

[2] DeBach, P. 1964. *Biological Control of Insect Pests and Weeds.* Reinhold Pub. Co., N.Y.

[3] Bodenheimer, F.S. 1938. *Problems of Animal Ecology.* Oxford University Press, London.

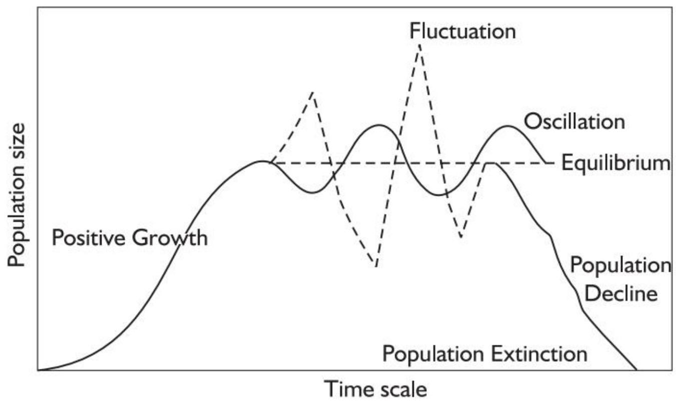
development, of reproduction and of post-reproduction. This has led to the preparation of 'Life Tables' dealing with the mortality relations and age structure. In the preparation of life tables a size group of over a thousand individuals at birth are considered and all data recorded such as age of insects in units, survivors at the beginning of the age interval, number dying at the age interval and the rate of mortality obtained by dividing the number dying in the age interval. A classic example of life table studies in insects is that in populations of *Tribolium confusum* and it is beyond the scope of this book to enter into such details.

Coming to the growth rate of populations of insects the general pattern appears to be sigmoid. Fundamentally in every population the growth pattern is divisible into various stages–increase in population or positive growth period or sigmoid phase, the period of rapid growth or logarithmic phase, the period of decreased growth, the period of negative growth or population decline, and the population extinction. Further populations are found to oscillate or vary symmetrically or fluctuate or vary asymmetrically and when they are at a minimum a stability or equilibrium is maintained in a population (Fig. 29.2). While the above mentioned are stages of growth patterns three distinct patterns of growth have come to be recognised.(1) self-limiting type whereby the growth rate decreases as density increases, (2) density-dependent type or non-self limiting type, and (3) the type in which the growth rate is high at intermediate densities (also called Allee's type).



▲ **Fig. 29.2** *Various phases of population growth (ibid)*

Intra- and interspecific competition in populations play an important role in determining the kinds and numbers of organisms. Some restrict their area of search for food and this area is known as the home range. Territoriality, which is very common in birds, occurs in insects also. Such behavioural patterns serve to regulate populations. For instance, with crowding, population pressure in *Sitophilus oryzae* leads to reduction in fecundity. As these oviposit in the grains, the reduction in fecundity appears to be due to competition for oviposition. On the other hand interspecific competition takes place among two or more closely related species adapted to the same niche and invariably leads to the elimination of one of the species. It therefore follows that two closely allied species cannot survive in the same niche and interspecific competition is a mechanism for separation of closely related species. This has come to be known as "Gause's principle" or the competition exclusion principle. It has been shown that in populations of grain beetles *Trogoderma versicolor, Tribolium confusum* and *Gnathoceros cornutus,* reared together to study the effects of competition, *Trogoderma* became eliminated first followed by *Gnathoceros* (Fig. 29.3).



▲ **Fig. 29.3** *Population trends in three genera of grain beetles (ibid)*

◆ Chapter 30

Ecology of Aquatic Insects

Primarily aquatic habitats are the lentic or standing-water habitats such as lakes, ponds, pools, etc. and the lotic or flowing water habitats such as rivers and streams, the latter comprising the perennial and intermittent streams according as to whether there is continuous water flow or temporary flows. Lentic systems are categorised in several ways, sometimes according to the relative degree of nutrients that they contain, For example, oligotrophic lakes have a low levels of nutrients and biological productivity and a high level of dissolved oxygen at all times; eutrophic lakes are rich in nutrients and biological productivity and have periodic low levels of dissolved oxygen. Most lentic systems are something between these two extremes, and highest numbers of aquatic insects are usually found in habitats that are at least somewhat eutrophic. Habitats of lentic insects are:

1. **Littoral Zone** : Numbers of lentic insect species tend to be the highest in littoral areas. The shallow shore area that extends to the limit of rooted aquatic plants is known as the littoral zone. Swamps, some ponds, and very shallow lakes are entirely or almost entirely littoral in nature. eg: May fly nymphs.
2. **Limnetic Zone** : The open water area up to the depth of light penetration is known as the limnetic zone. Relatively few floating or surface-dwelling insect species occur in the limnetic zone, although microscopic plant and animal life may be abundant. eg: pond-skater, giant water bugs.
3. **Profundal Zone** : The open, deep-water below the level of light penetration (including bottom) is known as the profundal zonal. There are generally very

few insects found in this zone, but some bottom-dwelling insects occur in abundance or at considerable depths. eg. certain mayfly larvae.

Transitional Phase from Aquatic to Terrestrial

Most aquatic insects leave the water in association with a major metamorphic phase - that is, a transformation to the sub-imago (mayflies), to the pupa (e.g., beetles, Megaloptera, and some Diptera), or to the adult (dragonflies and damselflies, stoneflies, caddisflies, and many Diptera). Many insects simply swim or crawl out of the water on to some exposed shoreline or object just prior to transforming to a terrestrial stage. Larvae of many insects, however, swim or float (sometimes aided by a bubble of gas) to the surface of the water and, after breaking the surface film, transform to a winged stage at the surface.

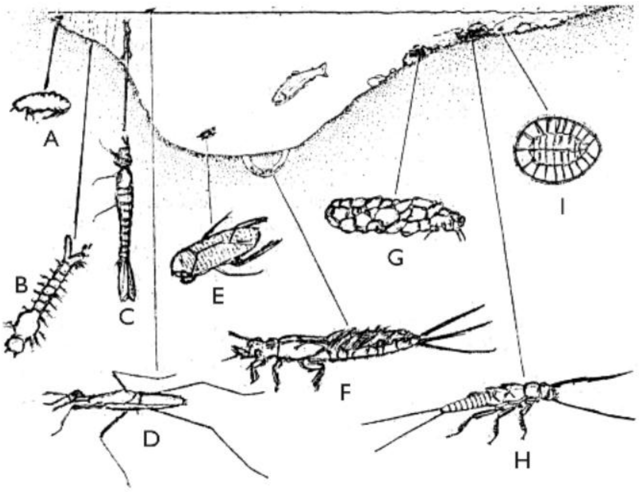
From Terrestrial to Aquatic

Many insects enter the water for the first time in their life cycles either as eggs or young larvae. Females of many aquatic insects oviposit in the water by dropping eggs on or into the water while in flight or after coming to rest on the water surface. Some females enter the water and dive or crawl to an adequate underwater surface for ovipositing their eggs (e.g., some mayflies, stoneflies, caddisflies, and aquatic moths). Females of some species oviposit in or on emergent floating vegetation (e.g., damselflies and many dragonflies, some water bugs, water beetles, and aquatic moths). Those larvae that come from eggs oviposited above the waterline in aquatic vegetation usually immediately crawl or fall into the water upon eclosion (hatching from the egg).

Eggs of some species are oviposited in or on moist shoreline areas or dry portions of stream beds (e.g., some stoneflies, water bugs, water beetles, midges, and a few caddisflies). Either the young larvae enter the water after eclosion or the eggs eclose only after becoming submerged. Megalopterans, some damselflies and a few caddisflies oviposit on vegetation or structures that overhang water; their eggs or young larvae eventually fall into the water. Eggs of some gaint water bugs are oviposited on the male’s back.

The Aquatic Environment

Most aquatic insects can be conveniently classified on the basis of their physical habitat and the means by which they move about or maintain themselves (Fig. 30.1). Members of each of these categories may have certain adaptive traits in common regardless of their taxonomic relationships.



▲ **Fig. 30.1** *Adaptive diversity in aquatic insects. A. Jumper (Collembola), B. Floater (mosquito larva), C. Climber (Damselfly), D. Water skater (Gerridae), E. Swimmer (Water boatman), F. Burrower (Mayfly), G. Sprawler (Caddisfly), H. Sprawler (Stonefly), I. Clinger (psephenid larva) (after McCafferty)*

A. Benthos Benthic insects (also collectively referred to as benthos) include those insects that are bottom dwellers. Substrates with which benthic insects may be associated include not only bottom surfaces but also any fixed or floating inorganic or organic object (e.g., stems of aquatic plants, driftwood, etc.).

(a) *Clingers.* Benthic insects that cling steadfastly to substrates in strong flowing waters or wave-beaten littoral areas of lakes can be termed clingers. Some are equipped with well-developed, grasping tarsal claws or with well-developed claws or hooks at the end of the abdomen. e.g. *Psephenus* sp (Psephenidae: Coleoptera) in the Himalayas; dragonfly nymphs and mayfly nymphs.

(b) *Sprawlers.* Benthic insects that crawl about on various surfaces of such substrates as rocks, fine sediments, woody debris, or leaf packs can be termed sprawlers. They occur in running and still waters, and many commonly reside on the undersides of rocks (e.g., larvae of some flat-headed mayflies, stoneflies and case-making caddisflies) or in porous areas of rocks or debris (e.g., larvae of some midges, stoneflies, and spiny crawling mayflies).

(c) *Climbers.* Benthic insects that commonly reside on aquatic plant stems, root systems along banks, filamentous algae, or mosses can be termed climbers. They usually inhabit the slower reaches or edgewaters of streams and rivers and are very common among the littoral vegetation of ponds, lakes, and swamps. A few examples of insects that fit in this category include larvae of many dragonflies and damselflies and some aquatic caterpillars. Water scorpions and a few other water bugs are climbers, but often must maintain partial contact with the water surface.

(d) *Burrowers* Benthic insects that burrow into soft substrates and live in this so-called interstitial habitat are termed burrowers. The substrate is usually silt, clay, or silt-sand; however, a few insects live interstitially at some depths in coarse sand or gravelly substrates. Burrowers generally inhabit ponds and lakes as well as the pools, slower reaches, and bank areas of rivers and streams. Examples of burrowers include the larvae of burrowing mayflies, some dragonflies, many midges, a few caddisflies, and some beetles. Some burrowing mayflies, caddisflies, and midges form well defined burrows or tubes.

B. Plankton/Nekton Aquatic insects that occur freely in the water fit into this grouping. Plankton refers to those that passively float or are freely suspended, and nekton refers more specifically to those that swim. Nekton and plankton are considered together, since many insects float part of the time and swim or actively move at other times.

(a) *Floaters* Some floating insects, especially those that must maintain contact with the air-water interface for respiratory purposes, live at or, near the water surface (e.g., many fly pupae, such as those of some shore flies and moth flies; and larvae of some flies, such as mosquitoes, and many marsh flies). Floating larvae, however, are active part of the time, and some, such as mosquitoes, may dive when disturbed. Adult whirligig beetles, which rest on the surface much of the time, are best categorised as swimmers. The eggs of some mosquitoes are laid as rafts that float on the water surface. Other floating insects live at considerable depths in ponds and lakes. Some floaters are equipped with hydrostatic organs, and some others swallow air bubbles that increase their buoyancy.

(b) *Swimmers* Most of the water beetles and water bugs that periodically surface for air are highly adapted for swimming. They have streamlined bodies and often possess legs that are oar-like and equipped with swimming hairs. Some insects that are otherwise benthic are capable of efficient swimming from one resting place to another. Some midges and case-making caddisflies are also proficient swimmers, and the adult whirligig beetles, which swim at the surface, are perhaps the most proficient swimmers of all.

(c) *Drifters* Lotic benthic insects that temporarily become suspended in the water and are carried downstream by the current are known collectively as drift. Drifting may result from catastrophic events, such as spates, severe lowering of the water level, or pollution. Many benthic insects, however, drift in a periodic manner under normal conditions. This kind of drifting is commonly known as behavioural drift. Drifting may be related to the density of individuals or the optimum carrying capacity of the aquatic habitat, to periodic predation pressure, or to downstream migration.

C. Neuston Aquatic insects that live on the water surface are referred to as neuston, or neustonic insects. These insects do not normally break the surface film. They, either walk, skate, or jump on the water surface. The claws or parts of the legs that come into contact with the water are moisture proof by virtue of the waxy layer of the exoskeleton or hairs, and they are often structured so that they bend rather than break the surface film. Insects that commonly walk or rest on surface film include water treaders and marsh treaders.

(a) *Skaters* Typical water skaters include the water striders and shortlegged striders. These two groups possess preapical claws; that is, the claws are not at the end of the leg but somewhat above the level of the tip, and they do not break the surface film. Skaters usually inhabit quiet water, but some are found on riffles.

(b) *Jumpers* Some species of springtails are found on the water surface and regularly jump off the water using a spring-like structure on the abdomen. Pygmy mole crickets also have the ability to jump off the water surface, using specialised hind legs to do so.

Trophic Adaptations

Many adaptations for feeding are found among aquatic insects. Some species are specific in their food preferences, and others are more general feeders. Food may be generated within the aquatic ecosystem or originate in an adjacent terrestrial ecosystem and subsequently fall or be blown into the water– for example, falling leaves and branches of overhanging trees as well as terrestrial insects. Food consists of either living material or dead and decomposing animal and plant material. Decomposing material is commonly referred to as detritus. Food items may be obtained either from the benthic substrate or from the seston (the materials suspended in the water).

Some food items are microscopic organisms, such as unicellular algae, bacteria, some fungi, and some zooplankton (planktonic animals), or microscopic bits of detritus. Macroscopic food items include most aquatic insects, many other aquatic invertebrates, filamentous algae, aquatic vascular plants, leaf detritus, and dead insects or other animals. Insects that feed on microscopic food items can be termed microvores, and those that feed on macroscopic food items can be termed macrovores.

Systems for classifying animals into feeding groups or trophic categories variously take into account the dominant kinds and location of the food, the method of feeding, and size of the food. It is difficult to incorporate all of these criteria into consistent feeding categories for aquatic insects.

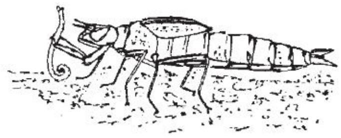
Herbivores

Herbivores, or herbivorous aquatic insects, feed on living plant material. Some species are obligate herbivores; i.e., their diet consists exclusively of plant material. Many herbivores will also feed to various degrees on animal material or detritus. Those that feed on both plants and animals are called omnivores. Those that feed on both living and decomposing plant and animal material can be called omnivore-detritivores.

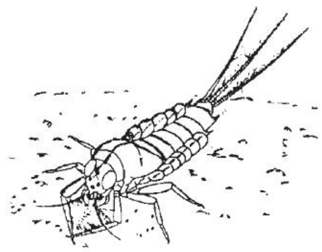
Macrovores: Herbivorous macrovores feed on aquatic vascular plants or some filamentous algae. Most of them chew solid plant tissue and are obligate (e.g., larvae of some case-making caddisflies, many aquatic and semi-aquatic caterpillars, the adults and some larvae of water beetles, such as some water scavenger beetles, aquatic leaf beetles, and water weevils; and many aquatic fly larvae). Some caterpillars, midges, and other flies bore into the plant on which they feed. Semi-aquatic Homoptera, such as some leaf hoppers and plant hoppers, feed by sucking the juices of emergent plants.

Microvores: Many of these herbivores are much more apt to be general in their food preferences and often select food items more on the basis of size and availability than on whether it is plant, animal or detrital in nature. Many feed on seston and are known as suspension feeders. Diatoms make up a significant portion of the diets of many suspension feeders. Prime examples of such feeders include the net spinning caddisflies and a few midge larvae that construct elaborate nets to capture seston floating downstream and black fly larvae, which use their mouth brushes for the same purpose.

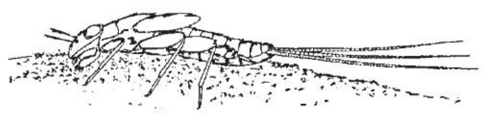
Many others in this category bottom feed on encrusted algae, including diatoms (usually along with microscopic detrital material). Bottom feeders include a large number of aquatic insects, such as larvae of many mayflies (Fig. 30.2), larvae of many case-making caddisflies, a few water boatmen, bottom-dwelling caterpillars, and larvae of many midges as well as other aquatic flies.



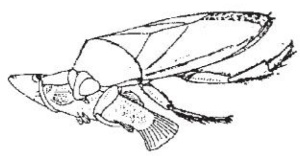
Dragonfly larva capturing midge with prehensile labium



May fly larve filtering food with hairs



May fly larve feeding on substratum



Predation by *Belostoma*

▲ **Fig. 30.2** *Feeding habits of some aquatic insects (after McCafferty)*

Carnivores

Carnivores, or carnivorous aquatic insects, feed on living animal material. Many are obligate, but some are omnivorous. In addition to attacking live prey, many will scavenge on dead animal material, and thus are technically also detritivores. Those carnivores that attack and immediately kill their prey are known as predators.

Macrovores: Predatory aquatic insects that attack other insects, small crustaceans, worms, and even small fishes are found in many orders. Many are partly cannibalistic; that is, they will attack members of their own species. Some predators are equipped with strong, opposable mouth parts for biting and chewing their prey. Other predators pierce their predators and suck body fluid with tube-like mouth parts grasping the prey in a pincer-like manner.

The larvae of dragonflies (Fig. 30.2) and damselflies are predators; some stalk their prey, and others rest secretively in ambush; all are equipped with an elaborate labium that is quickly extended to capture and hold prey. The larvae of all Megaloptera are predators with well developed mandibles and most water bugs (Fig. 30.2) are predators or predator-scavengers with well developed piercing and sucking mouth parts. Many water bugs (e.g. giant water bugs, creeping water bugs, and water scorpions) have raptorial fore legs adapted for grasping prey in pincer-like manner.

Most carnivores in this category are general feeders and can be regarded as omnivore-detrtitivores. They include many of the suspension feeders that filter microscopic food items from the seston e.g., larvae of many caddisflies, some mayflies (Fig. 30.2), and a number of Diptera. They also include species that do not filter but actively prey on small suspended zooplankton (e.g., larvae of phantom midges and some midges and mosquitoes).

Detritivores

Detritivores feed on detritus. The preferred detritus may be autochthonous or allochthonous, either plant or animal material. In most cases, the primary nutrient value of feeding on plant detritus is derived from the microorganisms (bacteria and fungi) that reside and grow on the detritus.

Leaf detritus is the most common food item for the majority of detritivores in this category. Some aquatic insects that feed on leaf detritus use other foods during periods when leaf detritus is not available. Examples of leaf detritivores are the larvae of many stoneflies.

A number of the surface-dwelling water bugs, in addition to preying on live insects, readily scavenge on dead insects that float on the surface film. There have been reports of a few aquatic insects feeding on dead fishes.

Small detrital particles are important sources of food for many species. In general, the suspension feeders (e.g., many caddisfly larvae) can be included in this category, as can be bottom feeders, such as the larvae of most mayflies and many caddisflies and midges. Many are herbivore-detritivores or omnivore-detritivores, as mentioned previously. Some, especially among burrowers and rat-tailed maggot larvae, ingest fine sedimentary material and derive nutrients from fine detritus contained there; these forms are sometimes known as deposit feeders.

Respiratory Adaptations

The generalised external respiratory system of insects is well suited for a terrestrial life and is essentially the system found in surface-dwelling aquatic insects and many semi-aquatic insects; however, either the system or the behaviour associated with obtaining oxygen has been modified. The respiratory adaptations of submergent aquatic insects, whether structural, behavioural, or physiological, are extremely varied.

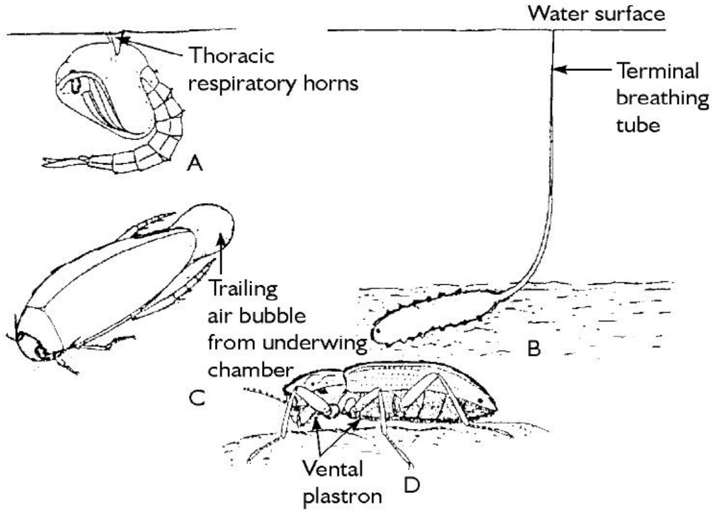
Aeropneustic Insects

Aeropneustic aquatic insects include submerged or partially submerged forms that use atmospheric oxygen (in the air). They possess functional spiracles, although the number and location of spiracles are often modified. Since aeropneustic insects are not limited by the amount of dissolved oxygen present in the water, they may be found in a wide variety of aquatic habitats.

Surface Air Breathers

These aquatic insects use atmospheric oxygen, even though they may be completely submerged or at least partially submerged most of the time. Continual-contact breathers, or tube breathers, maintain some bodily connection with the air-water interface. The point or points of air contact are either spiracles at the ends of tubes or open ends of tubes that lead to spiracles. The thoracic respiratory horns of many aquatic fly pupae are (Fig. 30.3) good examples of such structures, as are the terminal breathing tubes or siphons of water scorpions, mosquito larvae, many shore fly larvae, and rat-tailed maggots (Fig. 30.3). The tips of such breathing tubes are water proof or have moisture proof hairs that help maintain them at the surface.

Periodic-contact breathers, or air-storage breathers, are aeropneustic insects that live submerged but must swim, crawl, or float to the surface periodically to obtain air. These insects are able to carry an air supply under water, thus allowing them to continue respiration in a submerged state until the oxygen in their air store has been depleted. Air may be captured and stored in several ways. For example, many adult water beetles and water bugs, which constitute the large majority of periodic-contact breathers, capture a bubble in an underwing chamber (beneath the folded wings) (Fig. 30.3) or on other parts of the body, and a few beetle larvae and caterpillars obtain air with spiracles upon surfacing and store a surplus internally in enlarged trachea. A few flies also carry a bubble of air under water.



▲ **Fig. 30.3** *Respiratory types in aquatic insects. A. Mosquito pupa, B. Rat tailed maggot, C. Diving beetle with air bubble, D. Beetle with ventral plastron (after McCafferty)*

Dense coverings of microscopic, water proof hairs or scales hold the bubble of air to the insect's body while submerged. The densely covered areas may be extensive, but at least include those regions of the body where spiracles are located (e.g., the abdomen of bugs and adult beetles). The film of air held in such a manner is called a plastron. The plastron keeps the air spiracles dry and allows aeropneustic to take place under water (Fig. 30.3).

An important factor related to underwater air storage contributes to the ability of most periodic-contact breathers to remain submerged for an extended length of time: the air bubble, or plastron, acts as a physical gill. That is, oxygen present in a dissolved form in the water will to some extent diffuse into and replenish the bubble as long as nitrogen, which is also contained in the air bubble, has not dissipated. Thus the length of submergence of periodic-contact breathers is to some degree a function of the availability of dissolved oxygen, and they may not be entirely aeropneustic.

Some aeropneustic insects pierce vascular plants with modified spiracles and obtain oxygen available within underwater stems or roots. These are called endophytic breathers. Examples include the larvae of aquatic leaf beetles and larvae and pupae of some mosquitoes and shore flies.

Hydropneustic Insect

Hydropneustic aquatic insects are submerged forms that use dissolved oxygen. Some do not have functional spiracles, but many do. Generally they are limited in their habitat distribution to an extent by the amount of dissolved oxygen available in the water, and as a result are apt to be more common in lotic and well-aerated lentic habitats (with some exceptions). A few aquatic insects are capable of both hydropneustic and aeropneustic respiration.

Cutaneous Uptake

Most hydropneustic insects obtain oxygen directly through the body wall and are not reliant on functional spiracles. This so-called cutaneous respiration may occur generally over the softer, or membraneous, areas of the body. It is found in the permanently and totally submergent stages of most aquatic insects—that is, the larvae of mayflies, damselflies and dragonflies, stoneflies, a few water bugs, some water beetles, caddisflies, a few aquatic moths, and many aquatic flies. Some of the tube-breathing aeropneustic insects are also capable of cutaneous respiration in oxygenated water (e.g., soft-bodied aquatic fly larvae).

Many hydropneustic insects possess membraneous outgrowths on their bodies that add to the total amount of surface area available for cutaneous uptake and, in some larvae, serve as the primary sites for external respiration. Such outgrowths include most structures known as gills that occur on the larvae of mayflies, many stoneflies, dobsonflies, some caterpillars, many caddisflies, some beetles, and some aquatic flies. Other membranous appendages that have been termed filaments or lamellae (e.g., the caudal lamellae of some damselfly larvae) may also be respiratory sites.

Gills are basically of two types: i) Flat, plate-like structures that are commonly supplied with tracheal branches, and ii) Filamentous structures that are fleshy and tube-like but may be highly branched and may or may not be direct outgrowths of tracheal system. The so-called gills especially some plate-like gills have been shown to have other or additional functions, such as protection, swimming, clinging, stabilization, osmoregulation, or burrow maintenance.

Spiracular Uptake

Some hydropneustic insects use functional spiracles while continually submerged. Open spiracles are covered by a layer of air and never come in direct contact with the water, since the insects would otherwise be subject to drowning. The layer of air, or plastron, mediates the uptake of dissolved oxygen by acting as a physical gill (as discussed above under periodic contact, aeropneustic insects). A few insects possess branched outgrowths of the thoracic spiracles that are known as spiracular gills. Oxygen is obtained from the water via a plastron that is associated with the spiracular gills rather than a plastron, mediates the transfer of oxygen from the water to the insects.

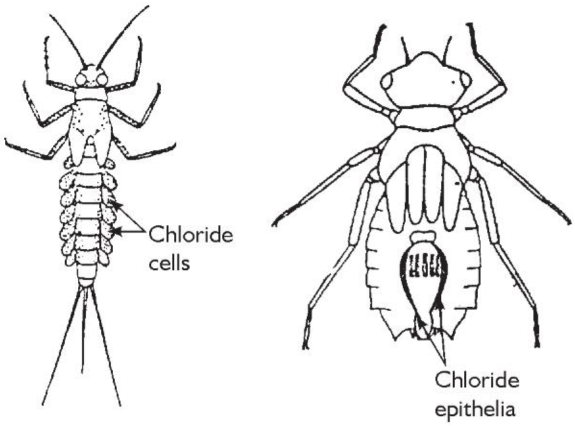
Osmoregulation

The phenomenon of maintenance of specific concentrations of internal salts or ions necessary for vital biochemical functions in animals is known as osmoregulation. Internal ions and water used metabolically and lost by excretion must be replaced. The availability of replacement ions and water depends partly on the specific kind of external environment in which the animal lives. As a result, osmoregulation is basically a matter of regulating the rate of intake and absorption of water or ions from the external environment and regulating their rate of excretion from the internal environment.

Chloride Epithelia

The larvae of damselflies and dragonflies and many caddisflies and aquatic Diptera possess various patches of integument that are rich in cells that function in the uptake of ions. These patches are known as chloride epithelia. The chloride epithelia of caddisflies vary in number and are located on the ventral and sometimes dorsal parts of the abdomen. These areas are actively ventilated. The chloride epithelia of aquatic flies are situated at the sides of the anal opening. The chloride epithelia of dragonflies and damselflies are located internally in the rectal chamber (Fig. 30.4). There are three such rectal chloride epithelia in damselflies; the number varies among dragonflies. Rectal chloride epithelia are ventilated by the rectal chamber.

Insects possessing chloride epithelia compensates for slight shifts in the salt concentration of the water by changing the rate of ventilation or by increasing or decreasing the size of the chloride epithelia. For example, the rate of rectal ventilation in dragonflies will increase as a response to decreased salt concentration in the water, and the size of the chloride epithelia of aquatic flies and caddisflies may increase as a response to a similar environment shift.



▲ **Fig. 30.4** *Osmoregulation in aquatic insects. Left: Mayfly larva with chloride cells; Right: Naiad with rectal chloride epithelia (after McCafferty)*

Papillae

Thin-walled, somewhat balloon-like outgrowths of the body that are located posteriorly on the abdomen of many aquatic insects like caddisfly larvae. These are known as papillae. Such papillae may occur as more or less permanent appendages posterior to the anus (e.g., anal papillae of midge and mosquito larvae); or as evagination of the rectal wall that protrude from the anus (e.g., preanal papillae of black fly larvae). Papillae range in number from 2 to 12 and are occasionally branched. The walls, or epithelium, of the papillae are capable of ion uptake. Insects can adjust to shifts in salt concentrations by an increase or decrease in the size of the papillae. For example, the papillae will increase in size in response to decreasing salt concentrations in the water, and will decrease in size in response to increasing salt concentrations.

Water Intake by Drinking

Ion absorption takes place in the gut of some predaceous diving beetle larvae and alderfly larvae. These insects must drink water to facilitate this process. It also follows that they must then excrete a considerable amount of dilute urine. In the beetle larvae, the ion absorption takes place in a part of the gut known as the ileum, which is relatively long and lined with a highly developed ion-absorbing epithelium. The rate of ion absorption may, in part, be regulated by the rate of drinking water.

Hypo-osmotic Regulation

Relatively few species of aquatic insects live submerged in salt or brackish waters (primarily the larvae of some Diptera, such as midges, mosquitoes, and shore flies). The osmotic gradient between the internal fluids of these insects and their aquatic environment favours the influx of ions and the outflux of water. Osmoregulation meant to conserve water and at the same time eliminate excess of ions is known as hypo-osmotic regulation. Most hypo-osmotic regulating insects drink the concentrated external medium.

Osmoregulation is also critical in aquatic environments both for the majority of aquatic insects that live in fresh water where the concentration of ions is lower than that of the insect's internal fluids, and for those insects that live in salt or brackish waters, where the concentration of ions is higher than that of the insect's internal fluids. The degree of tolerance for various concentrations of salinity in water and the relative ability of the insect to osmoregulate are important factors influencing the habitat distribution of aquatic species.

Hyperosmotic Regulation

In fresh water environments, a gradient between the internal fluids of the insect body and the external aquatic medium (known as an osmotic gradient) favours a flux of water into the insect body and a flux of ions from the body. The insect must therefore regulate the removal of surplus water and the intake and retention of ions. This type of osmoregulation is known as hyperosmotic regulation.

The removal of excess water is accomplished by the excretion of dilute urine, and ions are retained to some degree by reabsorption in the rectum or other parts of the gut. These functions cannot entirely compensate for ions loss, which is inevitable, hence freshwater insects possess additional osmoregulatory adaptations for active ion absorption.

Chloride Cells

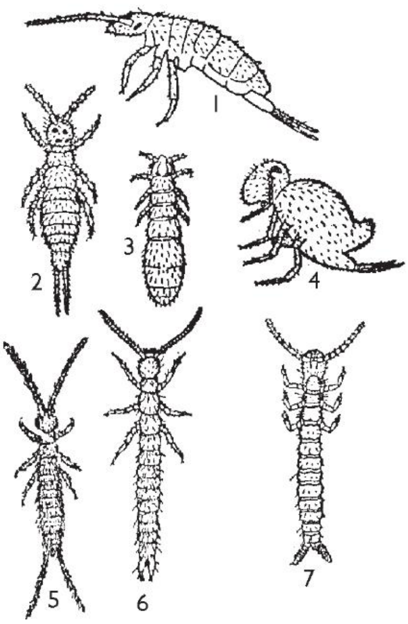
The larvae of mayflies, (Fig. 30.4) stoneflies, and the adults and larvae of submergent water bugs possess scattered, specialised cells, known as chloride cells, on various parts of their bodies. These cells function in the uptake of ions from the water. In mayfly larvae, chloride cells occur on different parts of the body, depending on the species, but they are usually concentrated on the gills and sides of the abdomen. The larvae are able to ventilate these areas when in still waters. Among stoneflies, chloride cells commonly occur on the lateral and ventral abdomen, inter-segmental areas, and gills. Among water bugs, chloride cells are distributed on any parts of the body except those covered by the folded wings or plastron.

◆ Chapter 31

Ecology of Soil Insects

Insects abound in soil and litter and it would be next to impossible to indicate the relative abundance of each species of the several orders represented. Broadly stating, the apterygotes, Collembola and Protura form numerically the most important groups of soil insects. Others like Dermaptera, Psocoptera, Dictyoptera, Isoptera, Coleoptera, a few Hymenoptera and some Diptera and Hemiptera also occur in the soil, sometimes as juveniles. The termites such as *Reticulotermes* and *Odontotermes* are important soil dwellers of tropics and play an important role in the break up of organic materials and their mixing up with mineral soils.

The Protura, Diplura and Collembola (Fig. 31.1) are the major soil dwellers. Japygids like *Anajapyx*, *Japyx* and *Campodea* are often found in small numbers in moist soils under stones and in humus and litter layers. Proturans are more abundant than Diplura and very common in moist forest and grass-



▲ **Fig. 31.1** *Some soil apterygotes 1.Entomobryidae, 2. Isotomidae, 3. Onychiuridae, 4. Sminthuridae (Collembola); 5. Campodea, 6. Japyx, and 7. Anajapyx (Diplura)* land soils which abound in species of *Eosentomon, Acerentomon* and *Acerentulus*. Of all the soil micro- arthropods, Collembola are the most predominant and stand comparison only with mites. The Onychiuridae, Isotomidae, Poduridae and Entomobryidae are richly represented in the soil both in number and species composition. The common species of Collembola found in soils in general are listed below.

Family Onychiuridae

Paratullbergia salmoni, Prabhergia nayari, Protaphorura ghatensis

Family Hypogastruridae

Hypogastrura communis, Willemia delamarei, Xenylla reducta

Family Brachystomellidae

Brachystomella terrafolia

Family Neanuridae

Lobella cassagnavi

Family Isotomidae

Folsomia baijali, Folsomides parvulus, Isotomella minor, Isotomina thermophila, Isotomodes dagamae, Subisotoma canituda

Family Entomobryidae

Alloscopus tetracantha, Aphysa ceylonica, A. travancorica, Cyphoderopsis decemaculata, Cyphoderus javanus, Dicrantocentrus spinosus, Indoscopus spinosus, Lepidocyrtus medius, L. scaber, Pseudosinella pattersoni, Salita celebensis

Family Neelidae

Megalothorax minimus, Neelus murinus

Family Sminthuridae

Dicyrtoma sp., *Sminthurinus trinotatus, Sphaeridia pumilis*

The type of soil, the composition of microflora, soil moisture and the type of vegetation influence the abundance of Collembola, although variation in pore size and organic content equally influence their variation in density in different soil types. Large forms like *Tomocerus, Entomobrya* and *Orchesella* abound in surface litter, while the smaller *Onychiurus, Tulbergia,* etc., occur in deeper layers. In the top 10-15 cm, Collembola abound in grassland and forest soils (Table 31.1), because this is the region where active breakdown of organic material takes place. The diameter of the pore cavities in this region is smaller and the moisture content of the organic layer is also less. *Life forms* have been characterized on the basis of distribution of Collembola involving progressive reduction in pigmentation, development of eyes and body size with increasing depth.

Table 31.1 Some Dominant Collembolans in Grassland, Forest And Cultivated Soils In India (after Ananthakrishnan, 1979)

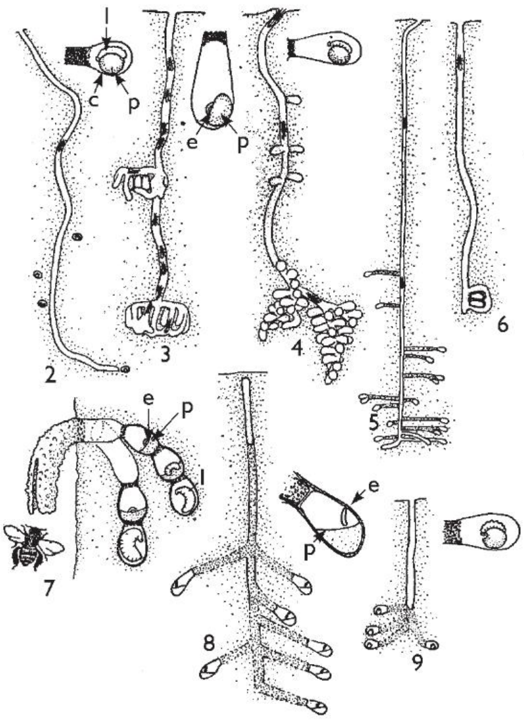
Grassland	*Forest*	*Cultivated Soil*
Lepidocyrtus suborientalis	*Lepidocyrtus* sp.	*Isotomina thermophila*
Cyphoderus albinos	*Cyphoderus javanus*	*Xenylla* sp.
Megalothorax minimus	*Brachystomella* sp.	*Proisotoma* sp.
Folsomides parvulus	*Lobella siva*	*Megalothorax* sp.
Isotomina thermophila	*Folsomides exiguas*	*Folsomides* sp.
Arthopalites sp.	*Sminthurus* sp.	*Pseudosinella* sp.
Pseudosinella sp.	*Sminthurides* sp.	*Isotomurus* sp.
Sphaeridia sp.	*Isotomina interrupta*	*Folsomina* sp.
Isotomurus ciliatus		
Isotomella minor		
Sminthurus sp.		
Brachystomella curvula		
Pseudochorutes sp.		
Tullbergia sp.		
Salita bengalensis		
Lobella maxillaris		

Among the Coleoptera, the carabids and staphylinids and to some extent cicindellids or tiger beetles are associated with soils principally along with a few others, like the larvae of click beetles or elaterids. Larvae of many of these beetles are subterranean, while the adults contribute significantly to the decomposition of organic matter by their litter feeding or xylophagous habits. The cockchafer beetles or scarabaeids have so wide a range of feeding habits that some of them are important members of soil community along with Elateridae, Carabidae and Staphylinidae. The grubs of the beetle *Arthrodeis* sp. (Tenebrionidae) feed on roots of rice seedlings in sandy soils.

Larvae of nematoceran Diptera like those of tipulids, mycetophilids, the brachyceran tabanids, asilids and empidids, and the Cyclomorpha represented by the muscids, phorids, the carrion feeding calliphorids and sarcophagids often abound in the soil. Maggots of the fruitflies such as *Bactrocera* spp. (Tephritidae) and some gall midges (Cecidomyiidae) pupate in soil. The mango inflorescence midge *Dasineura amaramanjarae* hibernates in the soil in its larval stage and gets carried over to the next year.

Among Lepidoptera the larvae of cutworms such as *Agrotis* spp., bollworm *Helicoverpa armigera,* leaf caterpillar *Spodoptera litura,* and many others belonging to Noctuidae, larvae of *Melittia eurytion* (Aegeriidae), the redhairy caterpillars *Amsacta moorei* and *A. albistriga* (Arctiidae), etc. pupate in the soil.

Among the Hymenoptera, ants are the most important soil dwelling forms though a few bees and mutilid wasps are also known to inhabit soils. Ants abound in forest litter and cultivated soils. Representatives of *Camponotus, Crematogaster, Formica,* etc. are wood dwelling and many members of Myrmicinae build mounds. The availability of food, the physical nature of the substratum as well as moisture content of the soil are important factors limiting the distribution of ants. The nesting habits of bees (Apoidea) are interesting and some bees dig their own hole as deep as 5 m into the earth. Males ordinarily do not help with nest building, defence, or provisioning. The bees that nest in earth belong to the genera such as *Amegilla, Andrena, Anthophora, Colletes, Halictus, Lasioglossum, Nomia, Nomioides, Systropha,* and *Tetralonia* and details of cells of nests of these soil-dwelling bees are illustrated (Fig. 31.2).



▲ **Fig. 31.2** *Nests of soil-dwelling bees with enlarged details of cells: c – cell, p – provision, e – egg; 1. Larva, 2. Systropha, 3. Nomia, 4. Halictus, 5. Nomioides, 6. Lasioglossum, 7. Anthophora, 8. Colletes, 9. Andrena. (S.W.T. Batra,Oriental Insects, Vol.11, 1977)*

◆ Chapter 32

Mycophagous Insects

The diverse and spectacular relationships of insects with fungi reflect almost a parallel, but a more mutualistic association than the insect-higher plant interaction. Despite the magnitude of the problem relating to mycophagy which affords sufficient opportunities to explore the ecobehavioural, physiological, and biochemical aspects of insect-fungal relationships in the field of forestry and agriculture, the significance of the interactions has not received due appreciation. The information available is mostly restricted to forest insects. Further, our understanding of the nutritional potential of the fungal tissues to correlate nutrition based reproduction, as well as the abilities of these insects to counter fungal toxins are far from complete.

Niches of Mycophagous Insects

Fungal tissues form the major food for many insects, the fruiting bodies of macrofungi providing food and shelter to several species. While woody fungi harbour a host of insects such as the collembolans, thrips, beetles, dipteran larvae, etc., short-lived fleshy fungi are inhabited by a large number of fly larvae including those of drosophilids feeding on the fruiting bodies which persist for 2-3 weeks. Several rusts and smuts causing blisters and cankers on plants are also exploited as food by insects. Obligate fungus feeders spending their entire lives or at least a part of the period of their life-history, occur in the fruiting bodies of some fungal species and these are the true mycetobionts. Many detrivorous wood feeding insects exploit fungi that normally grow on them, while there are many which actually culture fungi for feeding, since filamentous fungi are among the most nitrogen rich source of protein and sterols required by insects for their normal growth and reproduction. Some polyporoid or bracket fungi are known to harbour more than 250 species of insects, though not all at the same time. *Fomes fomentarius,* a polyporaceous wood inhabiting fungus is the best known and most widely distributed, causing rot of heartwoods and destruction of standing and structural lumber. Sporophores or fruiting bodies are preferred breeding places for insects. Ecological conditions of sporophores change with age and decomposition and succession occurs in relation to over 150 species of arthropods, the sporophore community comprising major mycophages, predators, parasites, scavengers, and tunnelers such as nitidulid and staphylinid beetles. The dipteran families of primary fungivores on the basidiocarps of fleshy fungi are Phoridae, Mycetophilidae and Anthophoridae, while the Drosophilidae and Tipulidae are secondary fungivores. Cecidomyiids have been known to be both secondary fungivores feeding on decaying basidiocarps and to be predatory. Nearly 85 years ago Tipulids were first discovered to be associated with fleshy fungi. Siricid wood wasps feeding on the fungus, *Amylostereum,* the *Macrotermes* group of termites which culture *Termitomyces,* ambrosia beetles including the platypodids and scolytids which culture different species of fungi within pockets on their bodies, fungus growing ants which culture them on freshly cut leaves and plant debris, and cecidomyiid galls harbouring fungal mycelia are typical examples. Besides, the mycetophagous and sporophagous thrips provide some of the finest examples of fungus feeding insects and of the nearly 2000 species known from the world, around 400 are known from India.

Nutritive Value of Fungi to Insects

The basic aspect is the contribution of the fungal food to the nutrition of the consumer insect. It is the capacity of the fungi to concentrate biologically important elements like nitrogen and phosphorus from extremely dilute substrates such as wood that is important. The nitrogen content of some fungal mycelia generally ranges from 1-7 per cent by weight, but may be very low as much as 0.25 to 0.75 in some fungi growing on wood. Low nitrogen levels in wood tend to limit the larval growth rates of beetles, but in the early stages of wood decay, they grow rapidly due to the fungal mycelium supplementing the meagre quantities of nitrogen in wood. It has been calculated that an insect would have to consume around 36 g of fungal mycelia in order to obtain an equivalent quantity of nitrogen present in 2.5 g of sporophore tissue or 1 g of spores. Carbohydrates constitute more than 50 per cent of most fungal tissues and hence they form a potentially rich source of carbohydrates for any organism possessing appropriate digestive enzymes to degrade fungal polysaccharides. Proteins form 20-40 per cent by weight containing all normal aminoacids. What is advantageous over green plants is the absence of condensed tannins present in many higher plants, which tend to combine with proteins to form complexes, reducing their digestibility and consequent availability of food to the insect. Fungal lipids contribute to triglycerides and free fatty acids required by insects and it is known that all insects require a source of sterols, and in the case of fungi it is ergasterol, a 28-carbon sterol that is the major sterol required for normal growth and reproduction. Since cholesterol is basic to the formation of juvenile and other hormones, the source of cholesterol for mycophagous insects is ergasterol.

Fungal Enzymes and Insect Feeding

The enzymes chitinases and glucanases are specific to fungal feeders. The digestive capabilities of mycophagous and phytophagous insects are different. Several beetles have demonstrated their ability to digest glucans and chitin, the major cell wall polysaccharides of higher fungi. But they are unable to digest cellulose, hemicellulose and pectins. What is of interest is that the enzymes provided by fungi continue to function in the gut of an insect which consumes fungal tissue. This strategy of resource utilization based on the acquisition of the required digestive enzymes is something unique. Fungi are excellent sources of stable enzymes and the acquisition of these fungal enzymes either by feeding on fungal tissue or on a substrate on which enzymes have been secreted tend to be of particular use to xylophagous and mycophagous insects, since they augment their digestive capabilities.

Adaptive Strategies

The fungus growing higher termites of the genus *Macrotermes* which lack trichonymphids have symbiotic association with fungi that grow in their nests in fungal combs. Such genera as *Macrotermes, Odontotermes,* etc., culture *Termitomyces,* a basidiomycetous fungus. By consuming the conidia and conidiophores of *Termitomyces,* the termites acquire hydrolytic enzymes active against cellulose. Though these termites are able to produce some of their own cellobiases and cellulases, some of the latter of which different kinds have been distinguished are derived from the conidiophores of *Termitomyces.* Wood rotting Basidiomycetes elicit certain behavioural responses in termites. The better survival and development of termites on decayed wood appears to be due to the greater nutritional value or a breakdown of some toxic substances by the fungi.

A good example of a truly symbiotic relationship between insects and wood rotting Basidiomycetes involves the siricid wasps which attack trees weakened by other insects. The genera *Sirex, Urocerus* and *Termex* are well known wood wasps which have a long ovipositor which penetrates bark and 1-15 mm into wood. The hatching larvae tunnel the wood and the tunnels contain mycelium of wood rotting fungi. Intersegmental pouches are evident at the base of the ovipositior containing oidia of the fungus. During oviposition the intersegmental pouches undergo contractions, forcing the oidia on the egg surfaces as they pass through the ovipositor, so that fungi are deposited in the wood along with the eggs. On germination of the oidia, the mycelium initiates a rapid breakdown of the wood.

Some species of *Sirex* have hypopleural organs on the first abdominal segment of the female, which contain the fungus *Stereum sanguinolentum*. The hypopleural organs are made up of a deep fold with a series of deep pits containing the fungal hyphae and oidia. These are subsequently drawn by continuous retractive movements of the ovipositor into the intersegmental pouches at the base of the ovipositor. Extracts of the midgut of siricid wasp larvae as well as of their fungal food *Amylostereum* revealed two major cellulases and three xylanases. It has been shown that the larva acquires requisite digestive enzymes through ingestion of fungi. As such, the acquisition and utilisation of fungal enzymes form an integral part of the highly evolved mutualism as in the case of termites.

An equally efficient strategy is seen in the leaf-cutting ants which cultivate fungi constituting one of the best examples of ectosymbiosis. The infrabuccal pouch of the ants is used as storage or repository organ for particles of substrate materials and with the filling of the pouch, the contents are discharged in the form of pellets containing fungal spores. The basic difference between fungus cultivating ants and termites is that the termites utilize their excrement as a substrate for the fungi, while the ants prepare a special substrate on plant tissues. As the fungi grow, no spores are formed, but characteristic club-shaped hyphal tips called *bromatia* are developed which constitute the edible portions of the fungus. The ant is known to receive from the fungus a diet with more than 27 per cent dry weight of carbohydrate, 4.7 per cent free amino acids, 13 per cent proteins, and 0.2 per cent lipids, and the fungus utilises 45 per cent of the cellulose content of the leaf material substrate. Though the leaf-cutting ants utilize a wide variety of plant material as fungal substrate yet they exhibit considerable selectivity. Species of the ant genus *Atta* and other fungus feeding ants manure their fungal gardens with faecal material which not only directly supplies the fungus with amino acids and other nitrogen sources, but also provides proteolytic enzymes which the fungus lacks. Without faecal enzymes of the ant, the fungus is unable to digest the proteins of the substrate. Two possible sources of these faecal enzymes are from microbial endosymbionts living in ants' gut, as well as intracellular fungal enzymes ingested by ants while feeding. The faecal enzymes actively degrade protein, chitin, starch, and xylan, and play a vital role in the maintenance of the ants' fungal cultures in their nests.

The ambrosia beetles–platypodids and scolytids–which bore deeply into the wood of fallen trees and logs, cultivating ambrosia fungi in the crevices to feed the developing young. The term 'ambrosia' coined in 1839, refers to the glistening white substrate, which later came to be recognized as fungal mycelia. These beetles have special ectodermal structures called mycetangia or mycangia which are usually developed in one sex, generally the female or in the sex which attacks the host plant first. The average number of ambrosia cells in the mycangium varies from 68 (*Xyleborus affinis*) to 160 (*Monarthrum*). Mycangia are mostly pit-like, classified according to their location: elytral, prosternal, subcoxal, prothoracic, pleural, pro-mesonotal, and oral. The number and distribution of the mycangia are of taxonomic value. The number tends to vary in the sexes, being always more in the female. Ambrosia fungi are highly species specific in relation to the insects, and flourish inside the wood tunnels throughout the active life of the beetles, the ambrosia consisting of hyphal bodies or chains of cells forming a compact lining to the tunnels. The ambrosia supplies the insect with a diet high on nitrogen content and the larvae reuses the excreted nitrogen for further growth. Relocation to new tunnels is effected during excavation and before oviposition. The perpetual association from generation to generation is made possible through the mycangia which carry viable inocula at all times. Most of the fungi are the Fungi Imperfecti such as *Lasiodiplodia, Monilia* and *Cephalosporium,* and the Ascomycete *Ceratocystis*. The tunnel systems tend to vary, with around 20 tunnels being common in the affected wooden substrate. The brood chambers are evident in a longitudinal section passing through the entrance pore, and these chambers are lined with ambrosia fungi. A single adult may lay up to a maximum of 40 eggs, and 16-20 adults occur in a gallery, and it takes 28–36 days to develop from eggs to adult. Heavily infested trees have 40–50 tunnels / 1000 sq. cm., and the average number of brood per gallery is 15–16 depending on the degree of branching. Many scolytids also harbour endosymbionts in the gut and these microorganisms not only supply the necessary vitamins, but also supplement nitrogenous components of larval diet. The platypodids utilise only ambrosia as food, since it supplies a highly nitrogenous diet, and reutilises the nitrogen excreted by the beetles for further growth.

Most species of the cecidomyiid *Mycodiplosis* feed on the mycelia of several species of mildews, molds and rusts. About 16 per cent of the entire group of gall midges are exclusively mycophagous. The gall midge *Camptodiplosis auriculariae* lives exclusively on the thalli of larger fungi like *Hirneola (Auricularia) auricula* that occurs on *Sambucus nigra* and *Ulma* sp. The larvae of *Brachyneuria peniophorae* cause small irregular galls on agaricalean fungus, *Peniophorae ovalis,* producing small blister galls on *Hypochnus fuscus.* Deuteromycetous fungi are intimately associated with the galls of midges, commonly referred to as the 'Ambrosia galls'. Adults of the midges *Lasioptera* and *Asphondylia* generally transfer the hyphae when the galls are initiated. In the galls the larvae draw nourishment not from the angiospermic host, but from the fungal mycelium that quickly establishes a luxuriant growth of mycelia within the gall and around the larva.

Several species of thrips occur in bark or dead branches of trees, and appear to be dependent upon fungal hosts for food, shelter, and a breeding place. Mycophagous thrips species are abundant in more humid situations and are seen in the tropical rain forests. In the Tubulifera species of *Hoplothrips* occur as larger aggregates often damaging the sporocarps. The phlaeothripines are essentially mycetophagous, feeding on fungal mycelia imbibing their contents, while the idolothripines are sporophagous. Feeding diversity in respect of fungal resource utilisation in diverse ecological niches is very typical of sporophagous idolothripines enabling recognition of such categories as:

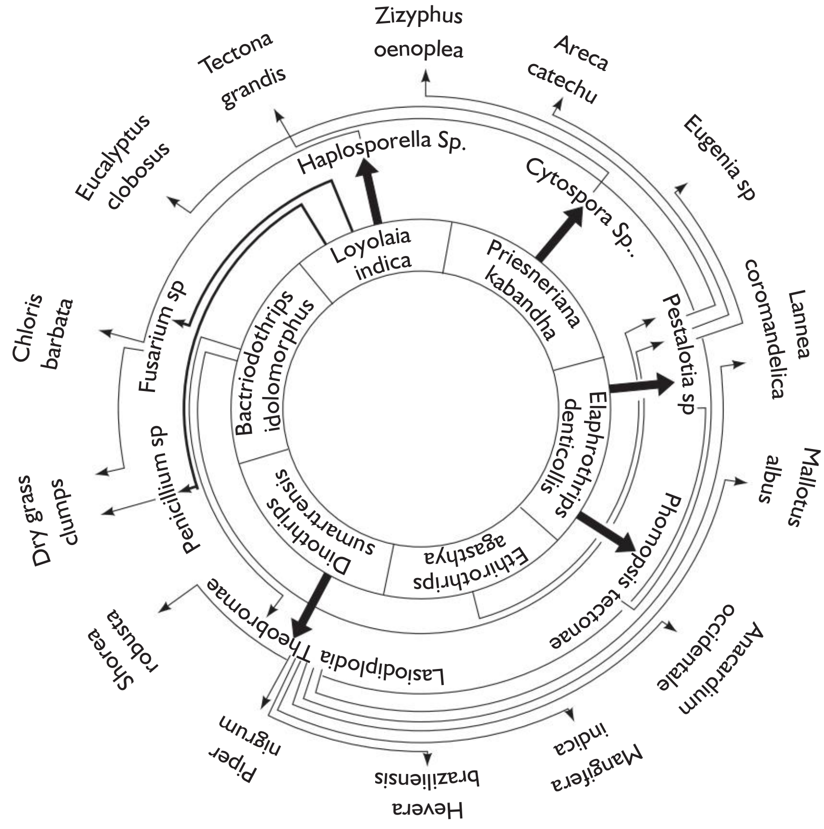
• Species which exploit various hosts for fungal food resource, but mostly feed only on the spores of one and the same fungus.

• Species which are more host specific, but feed on a wide variety of fungi present, involving all the major categories, Ascomycetes, Coelomycetes and Hyphomycetes.

• Species with a restricted host range and restricted to feeding.

• Species occurring on a wide range of hosts, mostly drying grass clumps.

The build-up of fungal inoculum of pathogenic species such as those of *Verticillium, Fusarium, Trichothecium, Lasiodiploidia, Aspergillus, Pestalotia, Phyllosticta, Phomopsis,* etc., at or near the sites of congenial hosts of thrips enables efficient mechanical transport of their spores by the associated thrips species (Fig. 32.1).



▲ **Fig. 32.1** *Sporophagous Thrips–Plant Pathogenic Fungal Associations (T. N. Ananthakrishnan, 1989)*

◆ Chapter 33

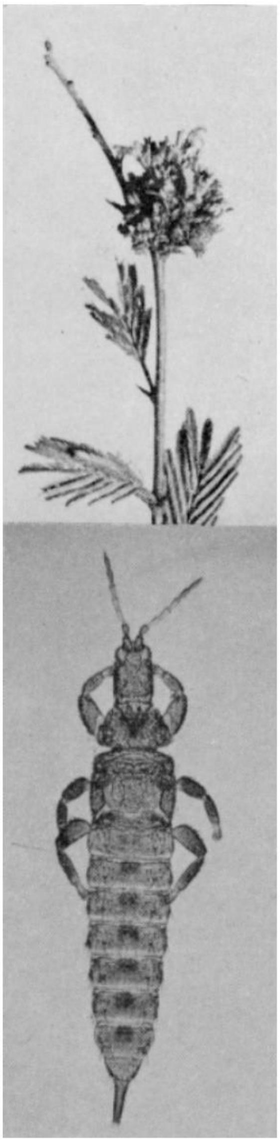
Insects and Plant Galls

Galls are abnormal growths produced by plants in response to the feeding or oviposition stimulus of insects resulting in excessive growth (hyperplasy) and cell multiplication (hypertrophy). Among the phytophagous insects, the cecidogenous or gall forming habit is rather scattered and some of the groups of recognised gall producers are thrips (Thysanoptera), aphids, aleyrodids, coccids and psyllids among the Homoptera, agromyzids, tephritids, anthomyiids and cecidomyiids among the Diptera, and sawflies (Hymenoptera). While these are the recognised gall makers, the curculionids or weevils and some lepidopterous larvae are known to be occasional gall makers. While the hymenopteran, dipteran and psyllids do not show diversity of gall forms, aphids, coccids and thrips show great diversity of forms, from crinkles, leaf folds, and leaf rolls to complex pouch galls. With the increased build-up of population within galls, further complexities arise in the galls. Although galls occur on all plant groups, Leguminosae harbour the bulk of them, followed by Moraceae, Lauraceae, Combretaceae, Anacardiaceae and Compositae. The gall surface may be glabrous, granulose, rugose, lobulate, convoluted, or pubescent, and as they mature some galls dehisce, while others do not.

Gall formation involves varied growth forms such as simple outgrowths, swellings, rolls or pouches or folds. In some there are excessively elongated undifferentiated hairy outgrowths called *erineal galls.* The simplest leaf galls are the *leaf-fold galls* as in *Mimusops elengi.* In *leaf roll galls* the blade rolls upwards or downwards from the leaf margin to the midrib as in *Piper nigrum* caused by *Liothrips karnyi* (Fig. 33.1).

Many complex leaf galls are sessile or stalked, swollen pouch-like pockets as in *Calycopteris floribundus* (Fig. 33.1). An interesting gall is the *rosette gall* formed by the arresting of the internodes and suppression of unfolding of leaf rudiments as in *Acacia leucophloea* galls (Fig. 33.2). In flower galls the individual floral parts cannot be recognised, with the complete fusion of and swelling of sepals and petals. Some galls are hollow, others solid. The *atriate galls* have an accessory space or *atrium* besides the gall cavity. Some galls burst open at predetermined sites (*dehiscent galls*). Others have a small

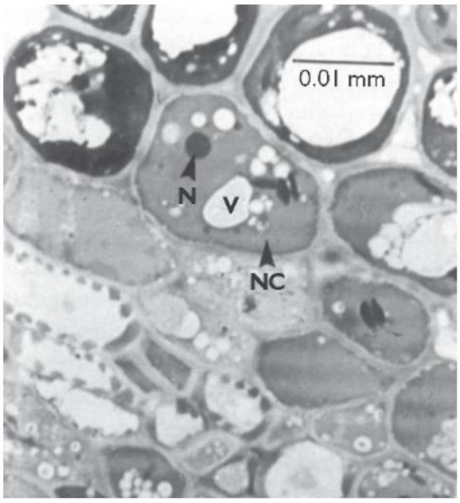
▲ **Fig. 33.1** *Pouch galls of Calycopteris floribundus induced by Austrothrips cochinchinensis (top); Epiphyllous roll galls of Piper nigrum caused by Liothrips karnyi (bottom) (T.N. Ananthakrishnan, 1978)*



▲ **Fig. 33.2** *Rosette gall of Acacia leucophloea (top) induced by Thilakothrips babuli (bottom) (ibid)*

opening, the *ostiole* through which the gall insects escape (*indehiscent galls*). Most galls contain other insects which do not contribute to gall formation. These are the inquilines. For e.g., on *Mimusops elengi* the primary gall maker is *Arrhenothrips ramakrishnae* and the thrips species *Androthrips flavipes* and *Liophlaeothrips vichitravarna* are inquilines.

Galls are induced on juvenile plant parts, very rarely on mature stems and leaves. An important feature is that gall-insects are very species specific, the mode of gall induction differing significantly among the groups of gall formers. Thrips choose very young developing tissues. Feeding stimulus induce gall production, with initially a few epidermal and hypodermal cells beginning to proliferate, contributing to gall growth. The proliferated tissues grow into specific gall types in different host plants depending upon the nature of the stimulus. Galls induced by aphids also synchronise their development with the availability of a new host flush with tender buds. Though the chemical influence in gall production is still a moot question, interesting information is available regarding the polyphenol oxidase in the saliva leading to the accumulation of IAA (indole acetic acid) in the host tissue, which in turn triggers gall induction. The action of gibberellic acid is also being suggested as a potential gall inducer. The continued presence of the gall insect is very essential for gall formation. By their feeding, gall insects induce the formation of the nutrient tissue which varies in different galls.



▲ **Fig. 33.3** *Ultrastructure of enlarged, cytoplasmically dense nutritive cells near feeding sites in leaf gall on Casearia sp. caused by Gynaikothrips flaviantennatus (ibid)*

The nutritive cells present varying profiles so that the layer of cells lying close to the feeding and developing insect, shows profound structural specialisation and adaptation. The nutritive cells show increase in cytoplasmic volume, presence of numerous active enzymes, increase in nuclear volume and chromatin content. Nutritive cells are rich in sugars and amino products, starch and lipids. The nature and distribution of the nutrients cells differ in thrips galls, as against others where they form a distinct layer close to the larval chamber.

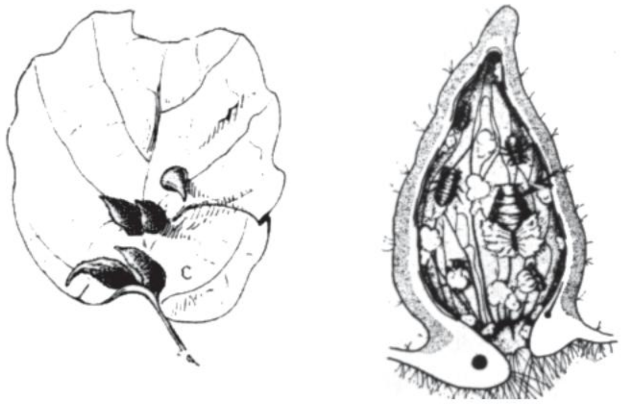
The life cycle pattern of some of the major gall producers are of interest. Gall forming thrips complete their life cycle in about 15-30 days and depending on the species, show 7-12 generations a year. New leaf growth in the host plant is one of the primary criteria that decides the population build-up within galls. While in most galls the number varies from 30-50, occasionally even 10,000 individuals may be present as in the pouch galls of *Calycopteris floribundus* produced by the thrips *Austrothrips cochinchinensis.*

Gall forming aphids are confined to the families Eriosomatidae, Adelgidae and Phylloxeridae. The life cycle pattern of a holocyclic eriosomatid gall aphid involves the characteristic migration between a primary host on which the gall is induced, and the sexual phase being completed on a secondary host without the formation of a gall.

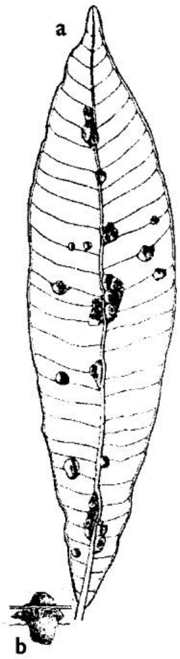
▲ **Fig. 33.4** *Galls induced by two species of the aphid Pemphigus on Populus Left bottom: Gall of P. spirothecae; Right top: Gall of P. bursarius (From J.D.Shorthouse)*

▲ **Fig. 33.5** *Pouch gall of Melaphis rhois on Rhus (ibid)*

The aphids *Pemphigus spirothecae* and *P. bursarius* (Eriosomatidae) induce galls on *Populus* sp. at the same time (Fig. 33.4). Pouch gall is caused by *Melaphis rhois* on *Rhus* sp. (Fig. 33.5). Similarly, pouch gall is induced by *Hormaphis hamamelidis* on leaf of *Hamamelis virginiana* (Fig. 33.6).

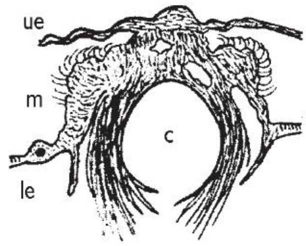


▲ **Fig. 33.6** *Left: Pouch gall of Hormaphis hamamelidis on leaf of Hamamelis virginiana Right: Section of mature gall showing the aphids inside the gall (ibid)*



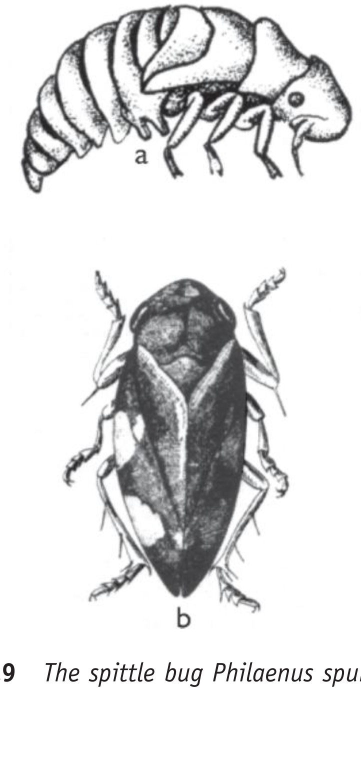
▲ **Fig. 33.7** *a. Truncated cone-shaped pouch gall of Pauropsylla tuberculata on leaf of Alstonia scholaris; b. Gall equally developed on both sides (ibid)*

In psyllids, about 2000 species are known in eight subfamilies, and they induce galls on a variety of dicotyledons. The psyllid galls of *Syzigium jambolanum* leaves and on species of *Ficus* are very well known. Continuous existence of the former gall is known with a maximum of ten generations a year. The gall of *Pauropsylla tuberculata* on *Alstonia scholaris* occurs on both sides of the leaf blade (Fig. 33.7). A covering gall from mesophyll cells is induced by a psyllid on *Trichillia* (Fig. 33.8).



▲ **Fig. 33.8** *Section of psyllid gall on Trichillia sp.: ue – upper epidermis, le – lower epidermis, m – hypertrophied and transformed mesophyll, c – larval chamber (ibid)*

Among coccids, out of 16 families, gall forming habit is confined to Margarodidae, Pseudococcidae, Eriococcidae, Coccidae, Asterolecaniidae and Diaspididae. Most galls are induced by the newly settled first instar nymphs. Interestingly enough males and females of some coccids like *Apiomorpha* induce separate, dissimilar galls known as *andro* and *gynocecidia* on *Eucalyptus.* Wind disperses the gall making first instar nymphs, referred to commonly as crawlers, from one host plant to another.



▲ **Fig. 33.9** *The spittle bug Philaenus spumarius (ibid)*

The spittle bug *Philaenus spumarius* (Fig. 33.9) causes growth inhibition and wrinkling of the host leaves. The larvae are protected by a mass of spittle (Fig. 33.10).

▲ **Fig. 33.10** *Wrinkled leaf of Oenothera sp. caused by Philaenus spumarius Arrows indicate the spittle mass secreted by the larvae (ibid)*

The most complex gall types are those induced by the Diptera, notably the cecidomyiids which are commonly called as gall midges. Gall midges have one or two, rarely several generations a year and some of them are polyvoltine. The gravid female oviposits in the plant tissue and adult midges live for very short periods, the males dying soon after mating. Contrary to the life span of adults, the immature stages live for very long periods for several months to even several years. Cynipids among Hymenoptera are endoparasitoids of different insect groups and the family Cynipidae includes the gall wasps and are considered as highly evolved and display very complicated pattern of life history. Alternation of generations involving a sexual generation of males and females with an agamic generation of only females is a very common phenomenon. This involves production of two types of females that differ not only morphologically, but also in the type of galls that their offspring produce. Agamic females emerging from the root galls are apterous and large. They crawl up the host trunk and oviposit inside the terminal or axillary buds, laying about 100 eggs at a time. Larvae emerging from these eggs induce gall development.

SOME GALL FORMING INSECTS

Thysanoptera

SPECIES	HOST
Aclystothrips aberrans Ananthakrishnan	*Ficus* sp.
Adelphothrips tristis Priesner	*Vernonia* sp.
Aeglothrips denticulus Ananthakrishnan	*Maytenus senegalensis*
Aliothrips elegantulus Priesner	*Ficus recurva*
Alocothrips hadrocerus (Karny)	*Maytenus senegalensis*
Anaphothrips marginemtorquens (Karny)	*Elatostemma sesquifolium*
Anaphothrips euryae (Karny)	*Eurya japonica*
Anaphothrips silvarum Priesner	*Galium verum*
Aneurothrips priesneri Bhatti	*Cordia obliqua*
Arrhenothrips ramakrishnae Hood	*Mimusops elengi*
Austrothrips cochinchinensis Karny	*Calycopteris floribundus*
Crotonothrips davidi (Ananthakrishnan)	*Santalum album*
Dixothrips onerosus Ananthakrishnan	*Terminalia chebula*
Gynaikothrips malabaricus Ramakrishna	*Ficus bengalensis*
Liophlaeothrips vichitravarna (Ramk.)	*Mimusops elengi*
Liothrips karnyi (Bagnall)	*Piper nigrum*
Mesothrips manii Anathakrishnan	*Santalum album*
Phorinothrips loranthi Ananthakrishnan	*Loranthus elasticus*
Thilakothrips babuli	*Acacia leucophloea*

Homoptera

Phylloxeridae	
Phylloxera vitifoliae	Grape
Coccidae	
Amorphococcus mesuae	*Messua ferrea*
Asterolecaniidae	
Lecaniodiaspis azadirachtae	Leaflet pit gall on *Azadirachta indica*
Aleyrodidae	
Aleuromarginatus tephrosiae	Leaflet pit galls on *Tephrosia purpurea*
Indoaleyrodes laos	Leaf pit gall on *Morinda tinctoria*
Psyllidae	
Pauropsylla depressa	Leaf gall on *Ficus glomerata*
Pauropsylla tuberculata	Leaf gall on *Alstonia scholaris*
Trioza jambolanae	Leaf gall on *Syzigium cumini*

Coleoptera

Curculionidae	
Alcidodes collaris & *A. pictus*	Stem galls on *Lab-lab niger*
Colobodes dolichotis	Stem gall on *Cajanus cajan*
Hypolixus truncatulus	Stem gall on *Amaranthus viridis*
Pempherulus affinis	Stem gall on Cotton (*Gosypium hirsutum)*

Diptera	
Cecidomyiidae	
Asphondylia ricini	Inflorescence of castor (*Ricinus communis*)
Asphondylia pongamiae	Gall on *Pongamia glabra*
Asphondylia sesami	Pod gall on *Sesamum indicum* (gingelly)
Asphondylia tephrosiae	Inflorescence of *Tephrosia purpurea*
Asphondylia trichocecidiarum	Gall on *Acacia leucophloea*
Dasineura mangiferae	Inflorescence of *Mangifera indica* (mango)
Erosomyia indica	Inflorescence of mango
Procystiphora mangiferae	Inflorescence of mango
Lasioptera cephalandrae	Stem gall of *Coccinia indica*
Lasioptera falcata	Stem gall of *Trichosanthes anguina* (snakegourd)
Lobopteromyia prosopoides	*Prosopis spicigera*
Orseolia oryzae (leaf sheath modified into tubular structures)	*Oryza sativa* – Rice gall midge
Tephritidae	
Bactrocera cucurbitae	*Cucumis sativus*
Lepidoptera	
Aegeriidae	
Melittia eurytion	Stem gall on snakegourd
Eucosmidae	
Grapholitha subrufilliana	Stem gall on *Crotalaria saltiana*
Gelechiidae	
Dactylethra candida	Stem gall of *Tephrosia purpurea*

◆ Chapter 34

Insect Behaviour and Social Life of Insects

INSECT BEHAVIOUR

Insect Behaviour relates to movements, whether of the antennae or legs or wings or of a whole insect in relation to its surrounding or of a group of insects as is exemplified by locust migration. The physiological basis of such movements is important, since it relates to the central nervous system and the way it processes the signals or inputs as well regulates outputs. The inputs are generally classified according to their action on the sensory system–*enteroceptors* (monitoring the physiological status of the insect), *proprioceptors,* providing information on various changes of parts of the body, and *exteroceptors* sensing events outside the insects, through visual, chemical and mechanical senses. The functional classification of behaviour becomes very useful in the area of chemical ecology, since it involves behaviour of insects in relation to diverse chemicals released by plants.

The direction of the movements of the insect or *orientation,* in response to external stimuli is important. These are mainly divided into kinetic and tactic movements or *kinesis* or *taxes*. When the direction of movements is not clearly related to the source of the stimulus, *kinesis* results. When the insect moves in a straight line in a favourable environment, it becomes unidirectional, but in an unfavourable environment, it begins to make turns, the frequency of which varies with increasing strength of the stimuli. Many insects orient themselves in response to different types of stimuli such as temperature, smell, humidity, etc. and such oriented movements are termed *klinokinesis.* When insects make use of directed reactions, tactic movements or taxes result. Examples of such movements are *anemotaxis* (in response to air currents), *tropotaxis* (when the insect is able to compare the intensity of the stimulus), *telotaxis* (movement towards a definite stimulus such as vision), *menotaxis* (light-compass reaction as of bees i.e. moving at a constant angle towards the source of light).

Behavioural aspects based on posture, movements, spatial relation with other individuals and special features of environment, such as plant texture, chemicals, etc. as well as consequences of behaviour, which may result in finding a mate are determined. In the case of flight for example, there are straight and rapid flights, circular, zig-zag, vertical flights, etc. Again, flight behaviour, and landing behaviour are induced by different stimuli, so that there is a need to understand olfactory and visual inputs, with the co-ordination and integration by the central nervous system. Multiple inputs and interpretation are also important as in the case of chemical-mediated behaviour, mating, feeding and egg laying.

SOCIAL LIFE OF INSECTS

Several insects form associations of diverse types involving an interdependence of individuals comprising them. Some are heterogenous associations of two or more different species as in the case of the scavenging mite and the predatory staphylinid beetle in the galleries of a caterpillar; or of several species usually found within galleries of scolytid beetles. The association of two or more species within plant galls involving the gall maker and inquilines is another example. The associations of individuals comprising of members of the same species as in ants, termites, bees, wasps, etc., are known as homogeneous associations. In these, the degree of interdependence among the different individuals is so great that they are unable to live outside the colony, thus losing more and more of their individual independence. A third type of association has been termed the complex type, as seen within an ant hill or termitarium within which are several kinds of commensals and parasites. Each colony of social insects is considered a self-sustaining biological unit. Division of labour is highly characteristic of such insect societies which show marked adaptations for feeding, defence, and reproduction. Specialisation of individuals in homogeneous associations occurs through the formation of castes, giving rise to social polymorphism, involving intraspecific co-ordination and co-operation, to the extent of their being considered as superorganisms.

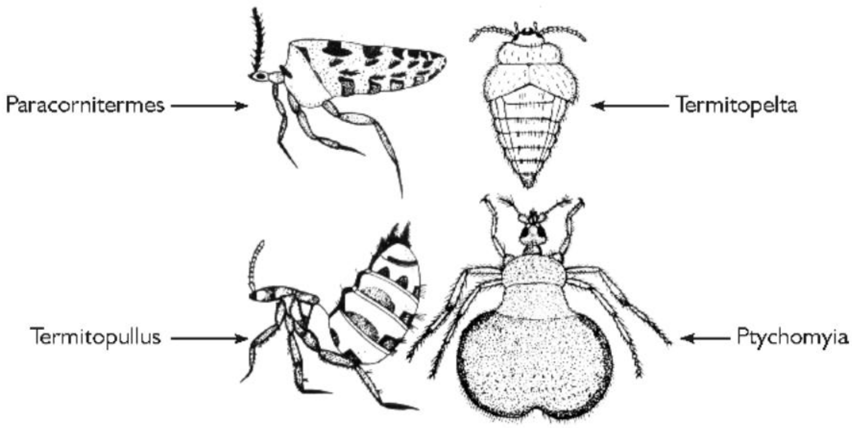
The nature of the castes in some social insects will be discussed in chapters dealing with the relevant insect orders. However, in general, it may be stated that among the females some are fertile and some sterile. In the primitive Hymenoptera, the sterile castes are termed the workers, which are always females. But in the termites, workers are found only in certain groups and these may be sterile males or females or as in primitive families of termites, the nymphs may perform the functions of workers. Among the wasps, when too many eggs are laid by the females, the larvae suffer from undernourishment leading to nutritional castration, so that the gonads do not reach maturity and they become the sterile workers. The main duty of the workers is to feed other castes and construct nests which may be simple or elaborate. Oral or mouth to mouth feeding is very characteristic of workers and is called *trophallaxis*. Protection or defence of the colony is the main function of the soldiers which are sterile males or females. Soldiers are absent in the bee and wasp societies, where the workers take over the function. Soldiers among termites possess a large head and very long, strong mandibles, but in some they are vestigial or absent and instead there is a frontal horn. These are the nasute soldiers. Sometimes characters of two castes are also seen in some members, known as intercastes. Workers among the bees are sterile females, produced as a result of restricted diet and have a dual function. They not only help in feeding the larvae, but also help in the maintenance of a constant hive temperature at 35° C by crowding together in cold weather, thus passing on to the hive their collective heat of metabolism. In warm weather fanning with the wings sets up a current of air which also serves in the evaporation of water causing a cooling effect.

Among ants, the soldier is always a sterile female. The workers are always highly polymorphic in many ant species, in particular like the army ant *Eciton* and the leaf cutting ant *Atta*. In these a fine inter-gradation occurs between the smallest and the largest workers, the latter being the soldiers, which not only defend the colony but also capture and transport food. In this connection mention may be made of functional polymorphism in the workers of some ant species serving as harvesting ants which forage and store food, the garden ants which sow fungal spores and cultivate mushroom gardens, the honey ants with huge bloated abdomens serving as receptacles of honey, the cow or herding ants keeping aphids for their secretions, and rearing them in 'stables'. In some ponerine ants there is an intermediate form between the queen and workers, with ovaries well developed and called 'ergatoids'.

The reproductive castes are the queens and males. The queens have a high egg-laying capacity, varying with species. The queen termite has often been called an egg-laying machine laying more than 30,000 eggs in 24 hr for several months in a continuous fashion. As such the greater the fecundity of the queen, the larger the colonies and organisation of the community would be. The only function of the male is to fertilise the queen and in some cases they help them in establishing the nest.

Termitophiles

Several commensals live in termite nests and these have come to be called termitophiles (Fig. 34.1). The major species include the staphylinid beetles, some Diptera, Thysanura, Collembola, Orthoptera, etc. Broadly speaking these are classified into *synoeketes* like the Collembola whose presence is merely tolerated, and the *synechthrans* like the carabid beetles whose larvae live in pits near the nests to catch and eat the termites. A third category are the *symphiles* exemplified by the fly *Termitoxenia.* In these, the abdomen is very much swollen – physogastry - and this bloating is so much that the abdomen is folded and overhangs the head hiding it. It is also interesting to note that these flies feed on termites and physogastry is the result of overfeeding. Staphylinids also take all sorts of forms and may be disc-like, with short limbs withdrawn under the disc, as in *Termitodiscus.* Sometimes very minute termites as *Microtermes* build their nests within the nests of bigger species and these are called kleptoparasites.



▲ **Fig. 34.1** *Termitophilous insects—Paracornitermes, Termitopelta, Termitopullus (Courtesy: Academic Press, N.Y.); and Ptychomyia (courtesy: Saunders & Co.)*

FACTORS AFFECTING CASTE DETERMINATION

It is generally believed that in cases where caste differentiation is well developed, determination of castes takes place quite early in the life history. The amount of yolk in the egg and the genetic make up of the zygote also appear important. In instances with weak caste differences differentiation takes place only after the adult stage. Sometimes as in *Polistes* it can occur either in the larval or adult stage. In the honeybee *Apis,* determination of queen bee is based on it being fed exclusively on royal jelly—a secretion of the pharyngeal gland of workers. But in the case of larvae developing into workers, the royal jelly is given only for two and a half days and they switch on to honey bread comprising honey and pollen. The transformation of the larvae into queens or workers can be brought about by this change in diet before the larvae are two to three days old. This illustrates the fact that caste differentiation starts very early in the larval stage. In some ants caste differentiation can take place any time till the last larval stage, in others in the first stage, sometimes even in the egg. The first eggs laid by a queen in some ants during colony establishment, develop into small workers. In *Myrmica rubra* the larvae become workers if the last-stage larvae do not undergo diapause. In *Formica rufa* the eggs laid in winter are large and those laid in summer are small. The winter eggs develop into queens and the summer eggs into workers. It is presumed that the yolk of the winter eggs have more RNA than in the summer eggs* (Weaver, 1966). In *Oecophylla* the unfertilised eggs of the queen develop into males and fertilised eggs into workers.

Evolution of Social Life in Insects

The occurrence of social life in such widely separate groups like Isoptera and Hymenoptera, is sufficient indication that it has developed independently along different lines. The basic factors involved in the organisation of insect societies are mutual co-operation of individuals and a high degree of division of labour which naturally demands an efficient system of communication serving as an integrating mechanism. This linking between individuals is achieved through external chemical transmission by way of pheromones. In addition to helping in the differentiation of castes, these 'sociohormones' stimulate specific receptors. The action of these 'hormones' has been discussed in detail in the chapters on behaviour and communication systems. But this much may be said that this chemical communication system plays a great role not only in regulating their behaviour, but also in the adaptive regulation of population structure in social communities through the control of reproduction.

Recent advances in the biology of social insects have clearly shown that they are super organisms having attained the pinnacle of biological complexity. This complexity necessarily involves semiochemicals which aid in the basic behavioural characters and regulating mechanisms. Communication involves directing workers to places outside the nest such as foraging. The food resources must be harvested in such a way that nest mates

* Weaver, 1966. *Ann. Rev. Ent,* **11**: 79–102.

should be mobilised in a co-operative fashion. Semiochemicals form the key basis of such co-operative endeavours involving community level interactions, resource partitioning, harvesting food resources, colony dispersion and establishing territoriality. Trail and territorial pheromones in social insects, especially in ants and termites are well known. However, such a communication has received very little attention in social wasps. The sternal gland is the source of trail pheromone in termites, the glands being differently placed in different termite genera, such as sternite V or III (single glands) or II, III and IV sternites. Trail substances elicit recruitment, tending to induce nest mates to get out of the nest. The principal trail orientation component from the Dufour's glands of ants is (Z, E) α-farnasene. In other ants the major component of the trail pheromone is methyl 6-methyl salicylate. In other ant species blends of pheromones exist, the hindgut trail pheromone comprising substances like decanoic, dodecanoic, heptanoic, hexanoic and octanoic acids. Several ants use trunk routes on trail systems which are marked with pheromones and the degree of persistence of the trail systems is variable.

What is the mode of discrimination of nest mates from non-nest mates? Cuticular hydrocarbons have been implicated as recognition cues in a number of ants, though more work is certainly needed in different species. There is diversity of these signals within species and it is on this intraspecific diversity of signals that nest mate recognition systems rely. Honey bees are capable of utilising signals acquired from food or other materials that are brought into the colony. To be effective as a signal, the insects must be able to not only perceive the compound, but also distinguish it from others, and the concentration of the compound. The source of the compound serving as recognition cues in social insects relate to cuticular hydrocarbons retained in or on the individual; nesting structures as beeswax; pheromones dispensed from queen; besides environmental cues such as floral oils, nest construction materials such as mixture of plant resins and so on.

◆ Chapter 35

Insect Migration

Large number of insects undertake migratory movements similar to those observed in birds. Locusts, butterflies and moths make long distance flights, and mass migration of dragonflies have been known for over a hundred years. Though migratory movements have been observed in several groups of insects, this habit is more pronounced and much information is available on locusts, butterflies and moths.

Migration of locusts was first discovered by Dr. B. P. Uvarov* in 1921 and each species of locust, such as the Desert locust (*(Schistocerca gregaria),* the migratory locust (*Locusta migratoria),* the Bombay locust (*Patanga succincta*) show two distinct phases — the *solitary phase* or *Phasis solitaria* when they are more isolated and behave like ordinary grasshoppers, and the *migratory phase* or *Phasis migratoria,* when they develop into huge swarms through crowding and are highly destructive to vegetation. In the solitary phase the locusts have a distinct dorsal carina, lacking in the gregarious forms. The tegmina of the solitary forms are also shorter than those of the gregarious forms. The solitaria phase is more juvenile and has to pass through an extra moult to become an adult. The locust swarms sometimes attain a width of more than a km and depth several hundreds of metres. The swarm moves chiefly in the direction of the prevailing wind. The primary reason impelling the gregarious forms to migrate is to discover proper breeding grounds; prior to this they get stimulated by mutual tactile stimuli resulting in the production of pheromones or ectohormones.

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* Uvarov, B.P. 1966. *Grasshoppers and Locusts.* Cambridge University Press, pp. 1–480.

The contributions of the pioneer Indian entomologist Y. Ramachandra Rao have added considerably to the knowledge of locust migration. Among his most important findings are: Non-swarming locusts carry out seasonal migrations fully comparable with those of swarms, taking full advantage of the seasonal shifts in the areas of rainfall which are essential for their breeding; and the solitary phase is also migratory, these migrations being due to the direct influence of seasonal winds. Thus he established a close connection between the pattern of locust migrations and the dynamics of the weather. The results of this important work were published in a major publication "*Locust Research in India*".

Several species of butterflies are known to migrate, *Danais plexippus* or the monarch butterfly being one of the most remarkable migrant butterflies. Though its home is the American continent, it has spread in all directions, east and the west. In Sri Lanka mass flights have been known to occur in more than 70 species of butterflies, among which those of the swallow-tails (Papilionidae), Danaidae, Lycaenidae and Nymphalidae are outstanding. In South India migrations have been observed in Kodaikanal hills at heights of 2500 m. During September- November when there is a shift in the monsoon thousands of butterflies come up from the plains, cross the mountain range and fly again down to the plains. Several butterflies of the family Pieridae (e.g., *Catopsilia*) undertake both flights. Flights of butterflies in North India involve movements up the foothills of the Himalayas at the beginning of the hot weather (March-April) and again move down in September to November, with the approach of winter (e.g., *Pieris brassicae, P. boeticus, Colias fieldi)*. Butterflies have been recorded above 4000 m in the Himalayas and on a glacier in Sikkim at a height of 6000 m. Among the moths *Agrotis ipsilon* has been known to migrate from Ganges Valley up the hills during hot seasons and back later.

Among the dragonflies the best known and most frequently recorded migrants are *Libellula quadrimaculata* and *L. deprina.* Large scale migrations of *Pantala flavescens* are found all over the world. Evidence of migration among beetles has been seen in the long distance movements of ladybird beetles, which appear to make to and fro movements from hibernating or aestivating localities. In some of the mass migration of insects, only a single species is involved, but in others many species fly together. An interesting observation has been the flight together of mimics and models in butterflies, when they migrate from the plains over to the Palni hills (Kodaikanal) in South India every year in October and November.

Various theories have been postulated regarding the orientation of migrating insects, but none satisfactorily explains the relationship between external causes and the internal mechanisms. It may be said that the orientation mechanism may change from time to time, being initially caused by the wind and then by the sun and other stimuli. There are also evidences to prove that low barometric pressure produces a state of activity in some insects. When migrating, insects fly high in the air as locusts and move to areas of low barometric pressure guided by the air currents.

Part 2

Taxonomy and Pestology

Section Five

Taxonomy

◆ Chapter 36

Taxonomy

Classification involves the arrangement of insects into clearly defined groups. This not only enables a proper understanding of as many insects as possible but also helps to have an idea of interrelationships of insect groups. All insects which possess well defined, constant characters of form and structure and which interbreed are grouped under a species. Species which resemble each other more closely and possessing certain common characteristics are associated in a higher category, the genus or genera. From the genus and the species the name of the insect is evolved to result in a double name, a generic and a specific name. This system of naming animals and plants was first discovered by Linnaeus*, a Swedish botanist, and the system is termed binomial nomenclature. The common cockroach for instance is named *Periplaneta americana.* As in all other animals in insects also we have closely-related genera grouped into families and closely related families into orders. Thus the systematic position of the common cockroach would be:

Phylum	Arthropoda
Class	Insecta
Order	Dictyoptera
Suborder	Blattaria
Family	Blattidae
Genus	*Periplaneta*
Species	*americana*

* Linnaeus, C. 1978. *Systema Naturae*, pp. 824

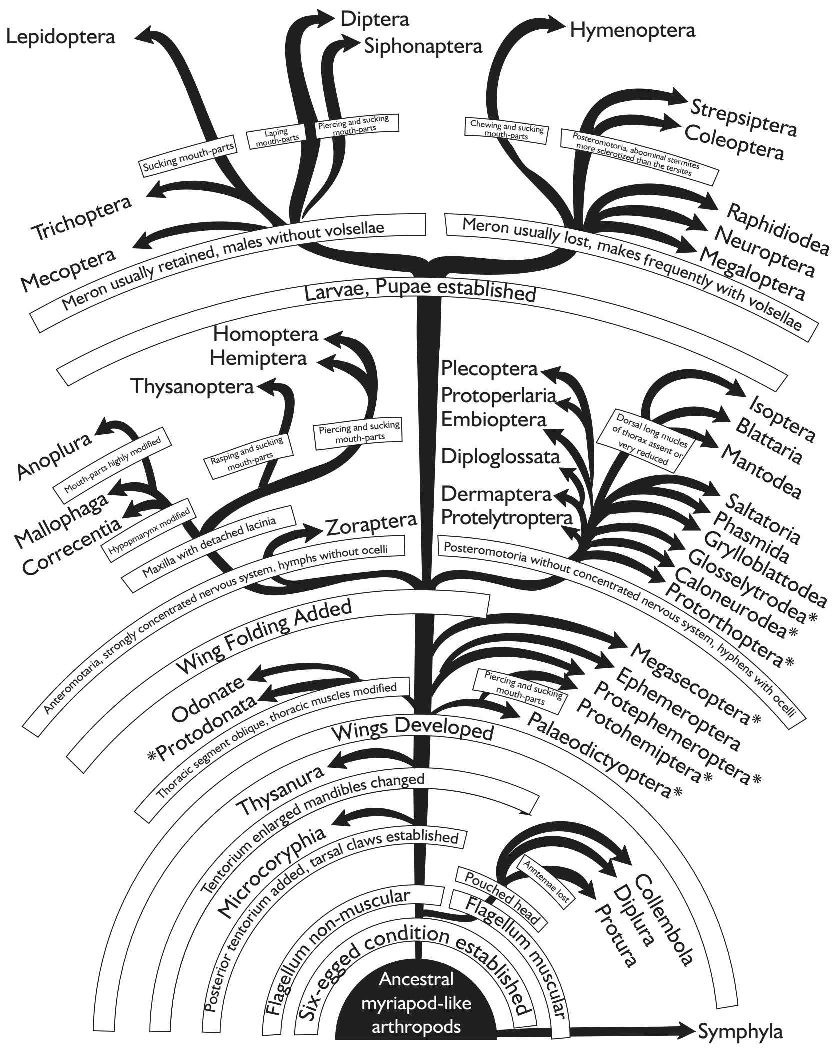
The validity of the names of the very large number of species and other taxa that have been in existence and that are added every year, is regulated by specific laws enacted by the International Code of Zoological Nomenclature.

Coming to the classification of insects, Linnaeus (1758) adopted a nine-order classification of insects, which though an unnatural classification without any bearing on interrelationships, was in vogue till about the end of the last century. The early Linnaean orders included: Aptera, Orthoptera, Neuroptera, Hymenoptera, Coleoptera, Lepidoptera, Diptera, Thysanoptera and Hemiptera. It is evident that emphasis was on the nature of the wings. In the later part of the nineteenth century attempts were made to increase the number of orders to accommodate many others like the dragonflies, lacewing flies, scorpionflies, stoneflies and so on. In this attempt Brauer (1885)[1] met with some success, because he clearly distinguished the two main subdivisions, the Pterygota and Apterygota, and in the classification of the pterygotes he emphasised the need for a natural system of classification involving such aspects as the nature of the wings, mouthparts, the degree of metamorphosis, the number of malpighian tubules and the complexity of the prothorax. He was able to recognise 16 orders of insects, though he was unable to classify the Apterygota further. It was left to Borner (1904)[2] to recognise the existence of ectognathous Thysanura and entognathous Diplura within the Apterygota, though the Collembola and Thysanura were distinguished as distinct orders much earlier. Berlese (1909)[3] included the Collembola and the Protura under two subclasses, the Oligoentomata and Myrientomata respectively.

The discovery of fossil insects paved the way for a natural system of insect classification and credit for evolving such a system goes to Handlirsch (1908, 1926),[4] Tillyard (1930),[5] and Martynov (1925, 1938),[6, 8] and this system was adopted by Brues, Melander and Carpenter (1954)[7] in their work on the classification of insects. The fundamental plan of

1. Brauer, F. 1885. Systematisch-zoologische studien. *S.B. Akad. Wiss. Wien*, **91**: 237–413.
2. Borner, C. 1904. Zur. Systematik der Hexapoden. *Zool. Anz.*, **27**: 511–33.
3. Berlese, A. 1909. Monografia der Myrientomata. *Redia,* **6**: 1–182.
4. Handlirsch, A. 1908. *Die fossilen Insekten and die phylogenie der rezenten Formen,* Engelmann, Leipzig, pp 1430.
4. Handlirsch, A. 1926. Vierter Unterstamm des Stammes der Arthropoda. Inseata-Insekten. In: Kiikenthal, W. and T. Krurobach. (eds.) *Handouch der Zoologie*, **4**: 403–592.
5. Tillyard, R.J. 1930. The evolution of the class Insecta. *Pap. Proc. R. Soc. Tasmania,* 1–89.
6. Martynov, A.V. 1925. *Z. Morph. Okol. Tiere,* **4**: 465–501.
7. Brues, C.T., A.L. Melander and F.M. Carpenter. 1954. *Classification of Insects,* Harvard Univ. Press, Cambridge, Masc.
8. Martynov, A.V. 1938, Trav. Inst. pateont Acad Sci *USSR.* **7**(4): pp 150

Martynov's system is based on the recognition of the Pterygota into two clear-cut groups—the Palaeoptera which are unable to flex their wings on the abdomen and the Neoptera with a wing flexing mechanism. The Neoptera were further divided into major groups, the Orthopteroid, Hemipteroid and Panorpoid complexes. The Orthopteroid orders formed



▲ **Fig. 36.1** *Phylogenetic tree showing interrelationship of the insect orders (courtesy: Alvaro Wille)* the Polyneoptera with numerous malpighian tubules and the wings with well-developed jugal areas; the Hemipteroids included the Paraneoptera with jugal areas reduced and with very few malpighian tubules; and also the Oligoneoptera which consists of all the holometabolous orders. The Panorpoid complex included Neoptera, Lepidoptera, Mecoptera, Trichoptera, Diptera and Siphonaptera. The Coleoptera and Strepsiptera formed a close group while the Hymenoptera, a problematic order, is usually associated with the Panorpoid complex (Fig. 36.1).

The following scheme of insect classification is now widely used by entomologists and incorporated in many standard works.

CLASS INSECTA

SUBCLASS APTERYGOTA

Order 1. Thysanura (bristletails)

Order 2. Diplura

Order 3. Protura

Order 4. Collembola

SUBCLASS PTERYGOTA

Exopterygote Insects

Palaeopteran Orders

Order 5. Ephemeroptera (mayflies)

Order 6. Odonata (dragonflies)

Orthopteroid Orders

Order 7. Plecoptera (stoneflies)

Order 8. Grylloblattodea

Order 9. Orthoptera (grasshoppers and crickets)

Order 10. Phasmida (leaf and stick insects)

Order 11. Dermaptera (earwigs)

Order 12. Embioptera (webspinners)

Order 13. Dictyoptera (cockroaches and mantids)

Order 14. Isoptera (Termites)

Order 15. Zoraptera (bark lice)

Hemipteroid Orders

Order 16. Psocoptera (book lice)

Order 17. Mallophaga (biting or bird lice)

Order 18. Siphunculata or Anoplura (suckinglice)

Order 19. Hemiptera (bugs)

Order 20. Thysanoptera (thrips)

Panorpoid Orders

Order 21. Neuroptera (ant-lions and lace wings)

Order 22. Coleoptera (beetles)

Order 23. Strepsiptera (stylopids)

Order 24. Mecoptera (scorpion flies)

Order 25. Siphonaptera (fleas)

Order 26. Diptera (two-winged flies)

Order 27. Lepidoptera (butterflies and moths)

Order 28. Trichoptera (caddis flies)

Order 29. Hymenoptera (ants, bees, wasps)

Note: Discovery of a new insect order Mantophasmatodea has recently been reported in *Science,* (**296**: 445–447, 19 April 2002,) which awaits recognition internationally.

◆ Chapter 37

Phylogenetic Systematics

The Field of phylogenetic systematics essentially involves methods for providing relationships. By this is meant the relative recency of common ancestry as for instance A and B are more closely related than to C if they share a common recent ancestor than either does with C. Shared derived characters among insects are evidence of common ancestry. The derived state, it can be implied, appeared first in the common ancestor and passed on to the descendent. Groups of organisms that are inferred to have been derived from a common ancestor and to be more closely related among themselves are called *monophyletic.* That means all descendents of a former ancestor are included with the taxon concerned. Against this is *paraphyly* and *polyphyly,* the former based upon shared ancestral characters and the latter on "misinterpreted characters", such as if we unite birds and bats because they share wings! Due to the dissent in interpreting characters as ancestral or derived, phylogeneticists depend on computers for assessing relationships. This has been called *numerical cladistics.* To the traditionally trained systematist, this method of inferring relationships would not appear very palatable.

It was Hennig* who introduced the system of classification relying entirely on geneology. His most basic criteria were: only groups based exclusively on the possession of "apomorphics" i.e. derived characters, should be recognised, while ancestral or *plesiomorphic* characters should be ignored. Each taxon according to him consists of a branch of the phylogenetic tree containing the stem species of this branch and all of its descendents. The basic difference between Darwinian taxonomists and Hennigian coun-

*Hennig.W. 1935. *Beitr. Ent.* **3**:1–85.

terparts, lies in the fact that by the traditional definition, a taxon is monophyletic if all its members are descended from the nearest common ancestral taxon, whereas according to Hennig a group is 'monophyletic' when it is composed of all the descendents of a single stem species. To avoid confusion the term 'holophyletic' has been adopted in recent years.

Hennig's term 'clade' does not correspond to the Dravidian taxon and in fact is referred to as *cladon.* Each cladon is traced back to the ancestral stem species. Clades rather than classes are the basis of Hennigian system. The term *cladification* is in vogue. To many, cladistic analysis is an excellent method of phylogenetic analysis and a fine method for the arrangement of species taxa with reference to their phylogeny.

Hennig particularly referred to paraphyletic groups such as Apterygota, in the sense that they are primarily wingless. They have a common stem species, but their descendents are not from the common stem species. The Apterygota share only primitive characters – plesiomorphics – and that is why they are not a natural taxon as per the Hennigian system. The Pterygota, however, share several derived characters – among them the wings – and this is why the taxon is a natural one.

◆ Chapter 38

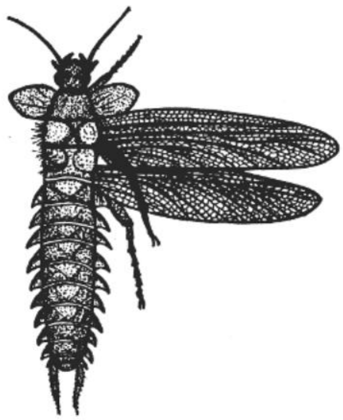
Insect Fossils

FOSSIL HISTORY OF INSECTS

The occurrence of insects in the fossilised state provides a more or less clear idea of the evolution of at least the main orders of insects. The oldest known insect fossils appear to be those of Apterygota. The blattids appear to be the oldest living insects, which have almost lived without undergoing large scale evolutionary changes from the carboniferous age to the present day. Some of the earliest apterygotes might have developed from the Permian or lower Carboniferous period. The richest collection of fossil insects are from the vegetable deposits like coal, lignite, peats and in amber entangled in the resin. Unfortunately many insect fossils are known only through their wings, resulting mostly in the study of the venation. However, the amber fossil of the Miocene present a more complete picture. The best known insect epoch is undoubtedly the Permian while the Triassic provides the richest discoveries of insect fossils.

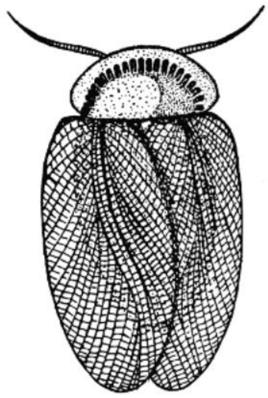
Extremely small and fragmentary records of insects were found in the middle Devonian from the fossil peat bog of Rhynie in Scotland and identified as *Rhyniella precursor,* now regarded as an early collembolan. It had a spring as specialised as any of the living collembolans and traces of ventral tube and retinaculum. The most significant feature is the nature of the antenna, with only three segments–scape, pedicel and flagellum, the latter showing annular furrows, reflecting the further segmentation in present day insects. Since living Collembola have four-segmented antennae, it may be assumed that they are derived from the primitive *Rhyniella.* Protura and Thysanura are not known from the early geological eras and are recognisable only from the lower Oligocene.

The Carboniferous period provides excellent examples of insect fossils, including insects of great size, with wings held horizontally while at rest. The principal fauna included the Palaeodictyoptera, Protorthoptera, Protodonata, Megasecoptera and Blattids. As has been mentioned earlier, the blattids still survive and are the oldest living insects. The Palaeodictyoptera are the most heterogenous of them, occurring in the famous fossil beds of Commentary in France. They are characterised by a small, rounded head with setaceous antenna; prothorax with conspicuous lateral notal expansions resembling fixed wing pads. The meso- and metathorax are subequal and the wings from these segments arise from broad bases and are elongate. The hindwings lack the fan-like anal lobe. The venation appears complete, with highly branched principal veins and an irregular network of fine veinlets, the archedictyon. The 10- or 11- segmented abdomen had lateral lobes similar to those of the prothorax. A pair of slender and elongate cerci, with sometimes a median caudal filament, were also distinct. Some of the common examples are *Stenodictya labata* (Fig. 38.1), *Homaloneura bonnieri, Homoioptera woodwardi* and *Lithomantis carbonaria.*

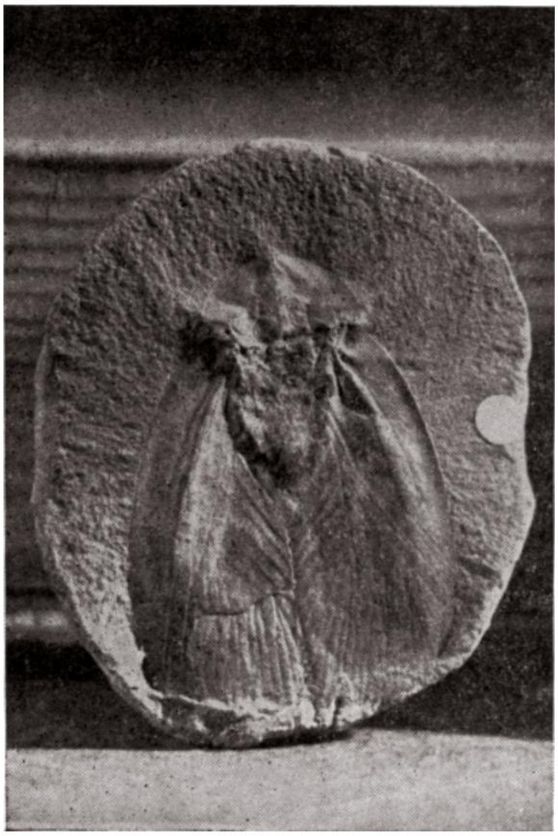


▲ **Fig. 38.1** *Stenodictya (R. Jeannel, 1960)*

The Protorthoptera, an early offshoot of the Palaeodictyoptera include orthopteroid forms, lacking the prothoracic notal expansions, a more specialised prothorax, distinct fan-like anal area in the hindwing, the wing venation as in most Palaeodictyoptera with an archedictyon. Some of the typical representatives of this order are *Dieconeura arcuata*, and *Protophasma dumasi*, *Dictyomylacris* (Fig. 38.2) *Aphthoroblattina* (Fig. 38.3). The Megasecoptera and Protodonata appear closely related, the former with an elongate cerci, narrowed wing bases and wings without dense network of veinlets; while the Protodonata have wings with very characteristic network of cross veins, arranged at right angles to the main veins.



▲ **Fig. 38.2** Dictyomylacris *(ibid)*



▲ **Fig. 38.3** *Aphthoroblattina (Aphthoroblattaria) (courtesy: Rentokil Labs. Ltd., East Grinsted)*

However, in the presence of a single anal vein, both approach each other. The Protodonata unlike the living Odonata lack the true nodus and pterostigma on the wings. The Megasecoptera include such species as ***B**rodia priscotincta*, and *Mischoptera woodwardi* while some of the Protodonata, in particular *Meganeura monii*, had a wing expanse exceeding two feet. The Protoperlaria appear ancestral to the living stoneflies or Plecoptera, though they are distinct in the presence of pronotal expansions. However, *Lemmatophora* exhibits closeness with the living Plecoptera, in the presence of cerci, fan-like anal area, and absence of median caudal appendage, irregular net work and also in the shape of the wings. The Protohemiptera, though essentially like Palaedictyoptera and Protoperlaria in appearance with the pronotal expansions, are unique in having mouthparts of the piercing and sucking type. The typical example is *Eugereon boeckingii* which had a small elongate head with mouthparts forming an elongate snout or rostrum in which could be recognised two pairs of stylets. The wings had a meshwork of transverse and cross veins.

The Protohymenoptera from the lower Permian period were initially believed to be ancestral to the Hymenoptera. Both these and the Protohemiptera though so called cannot be considered as anything more than independently evolved. The Protohymenoptera are reduced in size, slender and delicate-bodied forms. The presence of glossy, delicate wings, with pterostigma and similarity in the disposition of the veins, subcosta and radius are nevertheless hymenopteran features. Both the wings are closely alike in size, shape and venation. The Paramecoptera related to Mecoptera represented by *Belmontia* and *Parabelmontia*, ancestral to Lepidoptera and Trichoptera, and Protocoleoptera, represented by *Protocoleus mitchelli* are both from the upper permian beds, the latter having a flattened elytra with straight sutural margins. However, the venational patterns of these early coleopteroid fossils is totally different from those of existing Coleoptera.

Many other insect fossil groups exist which have only uncertain affinities.

Section Six

Insect Orders

◆ Chapter 39

Apterygote Insects

In the classification of insects dealt with here, a note of explanation is necessary. Insect taxonomy giving details of the various taxa are given in all the textbooks of entomology. In this connection mention must be made of books by Comstock,[1] Richards and Davies,[2] Essig,[3] Borror and deLong,[4] and Brues, Melander and Carpenter.[5] In the following account (Chapters 39 to 67) an attempt has been made to present a classification with a bearing on insects of economic importance. It tries to give an account of systematics and pestology focussing on biology and management of insect pests found in crops, forest trees, animals, stored grains and household material.

ORDER THYSANURA

BRISTLETAILS

Thysanura are small or moderate-sized active, terrestrial insects not exceeding 2 cm in length and include the popularly called silverfishes, firebrats, and bristletails. They may be covered with scales giving a look of shining uniform silvery or grey colour. However, most

1. Comstock, J.H. 1949. *An Introduction to Entomology*. Comstock Pub. Co., Ithaca.
2. Richards, O.W. and R.G. Davies. 1977, *Imms' General Textbook of Entomology*. B.I. Publications Pvt. Ltd., New Delhi.
3. Essig, E.O. 1942. *College Entomology*. Macmillan, N.Y.
4. Borror. D.J. and D.M. Delong, 1954. *An Introduction to the Study of Insects*. Holt, Reinhart and Winston, N.Y.
5. Brues, C.T., A.L.Melander and F.M.Carpenter, 1954. *Classification of Insects*.

thysanurans are brownish and the firebrats have body mottled with light and dark spots. The silverfish *Lepisma saccharina* (Fig. 39.1) and *Ctenolepisma longicaudata* are worldwide in distribution and are known household pests. They are destructive to paper, book-binding, starched cloth materials, lace curtains, etc. Bakery ovens are frequented by firebrats *Thermobia* sp. Many live in rotting wood, beneath stones, on grassy meadows, in leaf deposits of forest floors, and in soil. In the North-West Himalayas they occur as swarms feeding on dry moss, lichen and other vegetables debris, and the nival species *Machilinus hutchinsoni* is found usually at heights of 3,500 to 5,300 metres. Some are known to inhabit the nests of ants and termites. *Lepisma subnigrina* is myrmecophilus, found in the nests of the ant *Crematogaster* in South India.

Generally, thysanurans possess elongate spindle-shaped bodies but those belonging to the family Lepismatidae have depressed or more or less flattened bodies, while those of machilids are somewhat compressed. The head is prognathous and bears a pair of long filiform antenna each having 30 or more segments. Intrinsic muscles in the flagellar segments appear to be absent. The compound eyes are large and occupy most of the head capsule in machilids but are considerably reduced in lepismatids and are absent in some subterranean forms. The large ocelli, three in number, present in machilids are absent in lepismatids. The mouthparts are ectognathous and adapted for biting. The labrum is well developed and the mandibles have a single articulating point with the head in machilids or two as in lepismatids. The large maxillae bear five- to seven-segmented palps. The labium has a broad mentum and submentum and a paired prementum bearing distally the three-segmented palpi, paired glossae, and paraglossae in Machilidae or a single structure representing both, in the Ledpismatidae.

The thorax is closely articulated with the head, the broad thoracic segments bearing large paranotal lobes at their sides. The legs have a large coxa; a small, but free trochanter; a long femur and tibia and three-segmented tarsi in machilids and two- to four-segmented cerci in lepismatids ending in paired claws. A small, movable unsegmented style termed the stylus is borne on each of the coxal segments of the mesothoracic and metathoracic legs in some machilids. In others the stylus may be absent or found only in the hind pair of legs.

The abdomen consists of eleven segments and the small eleventh segment bears a pair of long filamentous, many segmented cerci and a multisegmented cerciform median appendage, which is a prolongation of the tergum. Ventrally each of the pregenital abdominal segments bears a pair of appendages; each appendage consists of a basal plate, the coxite and a small terminal stylus bearing short basal segment and a much longer terminal one. These appendages are believed to be vestiges of abdominal legs. Coxites and styli are present on segments two to nine in the machilids and styli are absent on the first abdominal segment. In the Lepismatidae they may be confined to segments seven to nine or eight to nine with the exception of *Nicoletia* where they are found in segments two to nine. Each appendage in addition may have one to two medially eversible vesicles extended by blood pressure and their function though uncertain appears to be respiratory. In many lepismatids the vesicles are wanting, the exception being *Nicoletia* which has two pairs of vesicles on segments two to seven. Most of the members of Machilidae have the vesicles on segments one to seven but in some as in *Petrobius* and *Machilis* they may be found on segments two to five each segment having two pairs of vesicles.

The external genitalia are modifications of the eighth and ninth abdominal segments. In the female the four gonopophyses or valves of the two segments together form the ovipositor. In the male only the ninth segment bears a pair of gonapophyses or 'parameres' having a median penis. However, in a few machilids a pair of small gonapophyses are found on the eighth segment. The penis is never withdrawn into its abdomen.

Nine pairs of spiracles are present in Machilidae (between the pro- and mesothorax, on the mesothorax and on the second to eighth abdominal segments). In Lepismatidae there are 10 pairs of spiracles found on the mesothorax and metathorax and the first eight abdominal segments.

Metamorphosis is slight. The young ones that hatch from the eggs are similar to the adults except in size, absence of scales, styli, and external genitalia. An interesting feature is their post-imaginal ecdyses, i.e. they grow and moult even after maturity. In the tropical species the life cycle is shorter being about a year and the insects may pass through six or more instars whereas for those in temperate zones it may be two or more years. The firebrat *Thermobia domestica,* which normally reaches sexual maturity after about 12 months, may at 37°C, have 45 to 60 instars and moult every 12–13 days. The female is oviparous and lays a batch of eggs after each moult and mates each time. The method of fertilisation in *Thermobia* is peculiar. The mating of the male and female is also curious, in that the male attracts the attention of the female by brushing his body against the legs of the female, which responds to this courtship. The male after half an hour of courtship deposits a single spermatophore on the ground a short distance ahead of the female and repeats the process of brushing her legs dashing more rapidly this time. This stimulates the female which now passes over the spermatophore seizing it by her genitalia. This recalls similar behaviour in some species of Arachnida.

There are about 350 species known so far and in India *Ctenolepisma* sp. is a common household pest. It measures 8-13 mm long, greenish grey or brownish. The eggs are deposited loosely in secluded places and the incubation period may be about a week. It reaches adult stage in 3-24 months. The insect population is controlled by surface spray application of propuxur 0.05% or poison baiting with a mixture of oatmeal, sodium fluoride or white arsenic, sugar and common salt.

The thysanurans belonging to the family Machilidae show certain independently evolved resemblance to higher Crustacea and they are also considered to be primitive.

The earliest fossil thysanurans date only from the Tertiary period but cannot be taken as an indication of their geological history. The recent fossil thysanuran known is from the Triassic period of the Urals.

Two Suborders viz., Microcoryphia and Zygentoma are recognised: the former is characterised by large eyes, presence of ocelli, seven-segmented maxillary palpi, coxae often with styli, and eversible vesicles usually on two to seven abdominal sterna; and the latter by small eyes (separate or absent), absence of ocelli, five segmented maxillary palpi, coxae without styli, and eversible vesicles absent or one pair present on some segments.

The Suborder Microcoryphia comprises the Superfamily Machiloidea, which is represented by two families viz., Machilidae and Meinertellidae.

Family MACHILIDAE

Possesses large triangular sterna, at least one and often two pairs of eversible vesicles on abdominal segments two to six. Examples are *Machilis, Petrobius, Dilta.*

The Suborder Zygentoma comprises the Superfamily Lepismatoidea, which is represented by three families viz., Lepidotrichidae, Nicoletiidae and Lepismatidae (Silverfish).

Family LEPIDOTRICHIDAE

In the U.S.A. a species *Tricholepidium gertschi* has been found to live beneath bark and rotting logs.

Family NICOLETIIDAE

Characterised by long gonopophyses in males. They are noticed to be myrmecophilous or termitophilous. Examples are *Atelura formicarius, Nicoletia.*

Family LEPISMATIDAE

Characterised by short male gonopophyses. Generally free living or domestic but rarely myrmecophilous. Examples are *Acrotelsa, Ctenolepisma, Lepisma saccharina* (Fig. 39.1), *Peliolepisma, Thermobia domestica.*

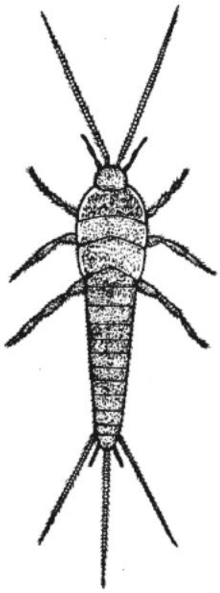


Fig. 39.1 *Lepisma saccharina (R. Jeannel, 1960)*

◆ Chapter 40

Order Diplura

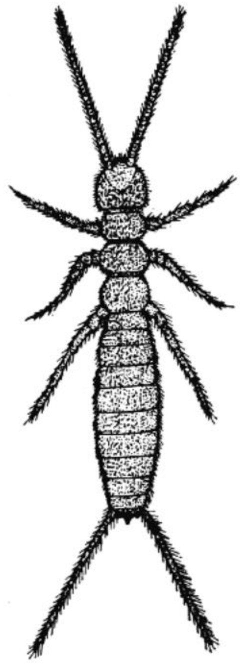
CAMPODEIDS, JAPYGIDS

INSECTS of this order are usually small, slender or fragile, wingless and lack body pigmentation. Some like *Heterojapyx soulei* are larger than the other apterygotes, measuring about 50 mm in length. They are widely distributed, very active and live under stones, among fallen leaves, in dead wood or in soil. They feed on fungus (campodeids) or may be predaceous or herbivorous (japygids). Usually the insects do not have scales on their body, but some belonging to the family Campodeidae have a few scales.

The head is prognathous, large, oval or quadrangular and freely articulated with the thorax. The antennae are moniliform, long, many segmented and are provided with intrinsic muscles. They lack compound eyes and ocelli. The mouthparts are entognathous, of the biting type and deeply withdrawn into the head. The labrum is a distinct sclerite. The mandibles are elongate and each articulates with the head capsule at a single point. A prostheca is present as a lacinia-like process of the mandible in members belonging to the family Projapygidae and in *Campodea.* The maxilla has one-or two-segmented palpus. The labium is small with reduced palpi which may sometimes be absent.

The three thoracic segments are distinct but the prothorax is the smallest and do not possess conspicuous paranotal lobes. The legs are similar with one-segmented tarsi ending in a pair of claws. The coxal styli are absent.

The abdomen is composed of ten conspicuous segments and the small, eleventh segment terminates into a pair of cerci. A caudal filament is absent. Ventrally paired styli are found on segments one to seven in Japygidae and Projapygidae and on two to seven in Campodeidae. Similarly paired eversible vesicles are found on abdominal segments two to seven in Campodeidae and *Anajapyx*, on two and three in the *Parajapyx* and on two alone in other japygids. Vesicles are lacking in *Projapyx*. The external genitalia and gonapophyses are always present. The cerci may be either long, multi-segmented and filamentous (Campodeidae) or short, forceps-like and single-segmented (Japygidae) or straight, few jointed and short with the apical portion perforated by the opening of a gland (Projapygidae). In Japygidae the sclerotised cerci are used in catching their prey. They are also sensitive to touch and to vibrations on the ground.



▲ **Fig. 40.1** *Campodea sp. (ibid)*

Respiration is by means of spiracles which are arranged in various ways on the thoracic and abdominal segments of the body of the insect and they present several unusual features in their arrangement. Three pairs of spiracles are present in Campodeidae and 8 to 11 pairs in others.

Metamorphosis is slight and much is not known about the life-history of the insect. Up to 20 eggs are laid in a shallow cavity in the ground which are guarded by the female or sometime after hatching. Campodeids moult every three weeks and take two years to attain definite chaetotaxy and fully segmented cerci.

About 600 species are known so far. The characters found in *Anajapyx* such as possession of abdominal styli, eversible vesicles, apical opening of glands on the cerci, structural details of mouthparts and legs, and presence of intrinsic muscles in the antennal segments makes it similar to Symphyla, and hence are of phylogenetic interest. However, the progoneate condition of Symphyla precludes it from being originated from a primitive Symphylan-like stock. A few recent workers opine that Diplura like each of the other Apterygote orders forms an isolated hexapodan group. Fossil Diplura are unknown.

Two Suborders viz., Rhabdura and Dicellurata are recognised.

The Suborder Rhabdura is recognised by mandible with prostheca, soft and setose abdominal styli and many-segmented cerci. The Suborder Dicellurata is recognised by mandible without prostheca, spiniform styli with few setae, cerci forcipate and single segmented.

The Suborder Rhabdura comprises of two Superfamilies Projapygoidea and Campodeoidea: the former represented by the families Anajapygidae (*Anajapyx)* and Projapygidae *(Projapyx, Symphylurinus)*; and the latter by Procampodeidae (*Procampodea)* and Campodeidae *(Plusiocampa, Lepidocampa, Campodea)* (Fig. 40.1).

The Suborder Dicellurata comprises of the Superfamily Japygoidea, which is represented by two families viz., Japygidae *(Japyx, Indjapyx, Burmjapyx, Metajapyx)* and Parajapygidae *(Parajapyx)*.

◆ Chapter 41

Order Protura

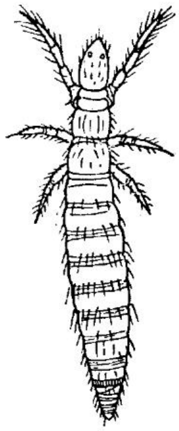
PROTURANS, TELSONTAILS

The protura are rare, minute, slender, primitively wingless terrestrial insects measuring 0.5 to 2 mm in length. They are met with under stones, beneath bark and in damp conditions in humus and soil. As the adults and young ones feed on decaying vegetable matter they are frequently noticed in decaying leaf mounds.

The proturans are whitish or yellowish, with a somewhat depressed and fusiform body (Fig. 41.1). The head is prognathous, cone-shaped or pyriform and narrows anteriorly. The compound eyes, ocelli and antennae are absent. A pair of minute structures called pseudoculi are found on the head which are considered to be vestiges of antennae. These structures are sensitive to light and as proturans remain in damp situations they avoid coming to light. Apparently the structures are homologous with postantennal organs of Collembola.

The mouthparts are of the entognathous piercing type. The labrum is pointed or vestigial; stylet-like mandibles have a single articulation with the head: the maxillae have only the inner or both lobes modified for piercing, and poorly developed; labium is membranous.

The prothorax is much reduced. The legs are long with single-segmented tarsi, each ending in a single claw and a bristle-like terminal pad. They walk slowly on the mid- and the hindlegs. This is due to the prothoracic legs being held upwards in front of the head simulating the antennae and hence probably function as tactile organs.



▲ **Fig. 41.1** *Dorsal view of a proturan (Fox & Fox, 'Introduction to Comparative Entomology', Reinhold Publishing Corp., New York)*

The abdomen is long and slender with eight segments and a telson when hatched. Three more segments get added up during the post-embryonic development by intercalary growth between the telson and the last segment. This phenomenon of addition of segments after emergence from egg is termed anamorphosis, and occurs only in proturans among the insects. Ventrally a pair of appendages is noticed in each of the first three segments. In Eosentomidae the appendages are two-segmented and the second segment is reduced with a protrusible vesicle. In others either the first pair or the first two pairs are two-segmented, the remaining being one-segmented with a minute lobe. Cerci are absent. The simple telson is a unique organ of the insect from which the name Protura is derived. In both sexes, the external genitalia are small and surround the gonopore, which lie between the eleventh segment and the telson. Some are without the tracheal system, but when present it is represented by two pairs of spiracles, a pair in each of the meso- and metathorax and each with an isolated set of tracheal tubes. Where the tracheal system is absent, respiration appears to be cutaneous.

The insects are oviparous, and metamorphosis is slight or anamorphic due to the increase in the number of abdominal segments.

The insects are widely distributed but generally overlooked due to their minute size. The first proturan was reported by Silvestri in 1907 from Italy. About 90 species are known so far mostly from Holarctic region and a few from Neotropical, Oriental and Australian regions.

Ewing in 1940 recognised the following three families.

Family EOSENTOMIDAE

Members of this family have tracheae and spiracles. The abdominal appendages are two-segmented and the eighth abdominal segment does not possess dorsolateral combs. Example: *Eosentomon.*

Family PROTENTOMIDAE

Characterised by absence of tracheae and spiracles and the third abdominal appendage being one-segmented. Combs much reduced or absent on the eighth abdominal segment. Typical abdominal terga each with a transverse row of setae and without transverse grooves or laterotergites. Example: *Proturentomon, Protentomon.*

Family ACERENTOMIDAE

Tracheae and spiracles absent. Third abdominal appendage one-segmented. Two transverse rows of setae on abdominal tergite, with one or two grooves and laterotergites. Combs are usually present on the eighth abdominal segment. *Acerentomon, Gracilentulus.*

All the three families are represented by Indian species.

◆ Chapter 42

Order Collembola

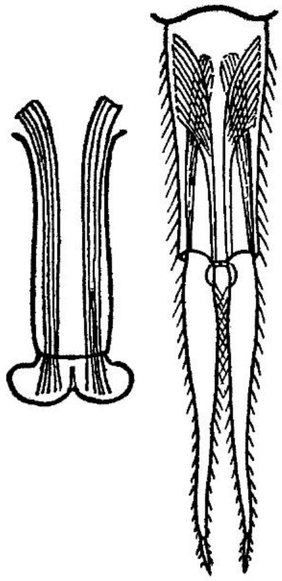
SPRINGTAILS, SNOWFLEAS

Collembola are minute, mostly elongate, or globose insects, rarely exceeding 5 mm in length. They are worldwide in distribution, occur commonly among decaying leaves and wood, in the crevices of bark, among herbage and moss in damp places, and are saprophagous, a few are known to be phytophagous. A few species feed on pollen, fungal spores, and mycelium. The species *Sminthurus viridis*, is a serious pest of lucerne and clover. Some other species belonging to the family Sminthuridae are also known to destroy tender leaves of garden plants. *Achorutes armatus*, is destructive to mushrooms. Some are known to inhabit ant and termite nests and occur even in fresh water and sea water. They are also known to exist at high altitudes on snow and are hence called 'snowfleas'. It may be interesting to know that Collembola flourish well at 6,000 metres in the North-West Himalayas at which height no other kind of insect is noticed. They inhabit the surface of stagnant water in glacial ponds and lakes, springs and glacial torrential streams, damp lichen and moss, snow and ice, decaying vegetable matter, nests of ants and rock surface in the North-West Himalayas. Here, even though they are often buried by avalanches they remain dormant till the ice and snow melt off.

They are green or yellowish with irregular patches of dark colour, a few are banded, white, or bright red but many of them are of a uniform dull blue-black colour.

The body of a collembolan consists of the head, thorax and a six-segmented abdomen, the latter being a unique character, not found in any other groups of insects. The body of the insect is clothed with hairs or scales of variable shapes. The head is prognathous or hypognathous and bears a pair of four six-segmented antennae, which may be shorter than the head or longer than the whole body and have internal muscles that move the segments. On either side of the head behind the antennae a group of eight or fewer distinct, simple eyes are present which represent more or less degenerate ommatidia, thus constituting the vestige of a compound eye.

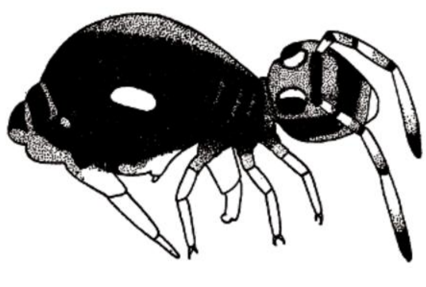
A characteristic simple, ring-like or rosette of a complex postantennal organ is noticed in some species which is evidently sensory, possibly of smell. The mouthparts are entognathous as they are deeply withdrawn into the head and typically of chewing type with reduced labium and maxillae. The slender mandibles have a single articulation with the head capsule and in some they may be absent. In *Neanura* and allied species a conical tube is formed of the labrum and labium together enclosing the stylet-like mandibles and maxillae which are used for piercing and sucking.



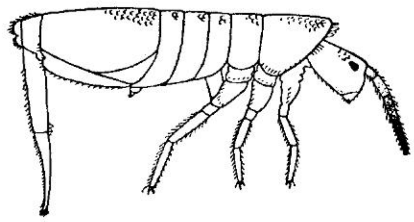
▲ **Fig. 42.1** *Left Collophore and Right Tenaculum of a collembolan (Snodgrass, 1935)*

The thoracic segments are similar in generalised forms but in others the prothorax is often much reduced. Members of the suborder Symphypleona have the thorax greatly fused with the abdomen. The legs are similar and have two subcoxal joints. Some authors report that a true tarsal segment is wanting but others suggest that the one-segmented tarsus is fused on the tibia to form a tibio-tarsal segment, and ends in a pair of post-tarsal claws, of which the inner one may be sometimes wanting.

A very characteristic collembolan feature is the six-segmented abdomen by which it is distinguished from other insects. Ventrally in the first abdominal segment is present the ventral tube or collophore, viz. the glue-bar and the name Collembola is derived due to the presence of this organ only. The collophore (Figs. 42.1, 42.2) is tube-like with eversible sacs at its tip which are everted by enhanced blood-pressure. The collophore



▲ **Fig. 42.2** *Sminthurus trinotatus (courtesy: N.R. Prabhoo)* has been considered to be an adhesive organ enabling the insect to walk over smooth and steep surfaces. The sticky fluid is the secretion of the cephalic glands and passes mid-ventrally through the ventral groove that arises just behind the labium and terminates on the anterior aspect of the collophore. Though it is suggested that the collophore is concerned with water absorption, recent views attribute a respiratory function enabling the insect to breathe at times when the general body surface is too dry for cutaneous respiration. A tracheal system is absent in Collembola as respiration is usually cuticular, and if present (which is rare), it is represented by a pair of simple apertures in the cervical region as in *Sminthurus.* A pair of short appendages are present on the ventral aspect of the third abdominal segment of many collembolans and is referred to variously as tenaculum, catch, retinaculum or hamula (Fig. 42.1, 42.3). It is fused basally to form a corpus and the free distal portions are called the rami. This organ serves to retain the springing organ in position. The springing organ or furcula represents the partially fused appendages found on the ventral aspect of the 4th abdominal segment. It enables the insect to leap into the air suddenly and hence the common name 'springtails'. The furcula has a basal manubrium and a pair of distal arms or dentes, the latter carrying a claw-like process or macro on each arm. The furcula may be wanting in a few and especially in those which are found at high altitudes.



▲ **Fig. 42.3** *Lepidocyrtus medius (ibid)*

In Collembola the sexes are separate and similar without definite external genitalia, although the gonopore is located on the fifth segment. The anus in located on the sixth sternum. Cerci are never present.

Scattered spermatophore packets deposited by the male on the ground are accidentally imbibed by the females. In a few forms parthenogenesis has been suspected but it has not yet been proved. Generally a preponderance of females occurs. The animals may moult as many as fifty times; generally three growth stages have been recognised: juvenile, mature and senile forms. Senile forms do not grow but moult several times. Of the many environmental factors, temperature produces a striking effect known as ecomorphosis. Under increased temperature conditions, forms like *Onychiurus* and *Friesea* show abnormal phenotypes with marked changes in form and histology. Mass emergence known as swarming occurs in some spring-tails as in *Hypogastrura socialis* and nothing is known about the causes of this outbreak. Life forms have been recognised in Collembola based on ecology of the insects like epigeon (eyed forms in relation to vegetation), neustomic (on water surface), xeromorphs (in association with lichens), euedaphon (deeper soil forms), troglomorphs (cave living), and synoecomorphs (in association with ants and termites).

More than 1,500 species of Collembola have been described so far. Over 36 species have been reported to occur in the nival zone of the North West Himalayas. In South India several species like *Isotomiella minor, Lepidocyrtus* sp., *Sphaerotheca* sp. and *Hypogastrura armata* have been recorded.

Collembola are regarded as a specialised offshoot from the base of early Symphylan stock. It would also be interesting to know that the oldest fossil insect, the Devonian *Rhyniella praecursor*, which is about 300 million years old, is a collembolan.

Suborder ARTHROPLEONA

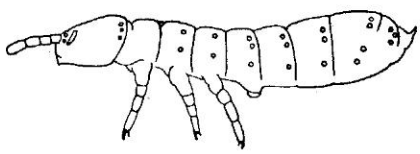
Body more or less elongate; distinct segmentation

Superfamily PODUROIDEA

Have free well-developed pronotum with setae

Family ONYCHIURIDAE

Have pseudocelli (i.e. apertures in body wall) on thoracic and abdominal terga. *Onychiurus* (Fig. 42.4).



▲ **Fig. 42.4** *Onychiurus sp. (ibid)*

Family PODURIDAE

Pseudocelli absent; head hypognathous and furcula extending beyond ventral tube. Example: *Podura.*

Family HYPOGASTRURIDAE

Lack pseudocelli; more or less prognathous head; furcula, if present, rarely reach ventral tube. Example: *Hypogastrura.*

Family NEANURIDAE

Psudocelli absent; piercing mouthparts. Represented by genera such as *Anurida, Neanura, Friesea, Pseudachorutes, Brachystomella*

Superfamily ENTOMOBRYOIDEA

Pronotum reduced or absent and lack setae.

Family ACTALETIDAE

Third abdominal tergite much reduced and abdominal segments four to six fused; hypognathous head and have tracheae. Example: *Actaletes.*

Family ENTOMOBRYIDAE

Third abdominal tergite not much reduced and abdominal segments four to six free; Fourth abdominal segment longer than third; a group of setae on trochanter called trochanteral organ present. Examples are: *Entomobrya, Lepidocyrtus, Siera.*

Siera iricolor is a pest of button (*Agaricus bisporus),* oyster (*Pleurotus)* and tropical mushrooms (*Volvaria volvacea*) in the Punjab since 1994. The adult measures 2.86 mm in length and 0.4 mm in breadth. Egg measures 0.18 mm in diameter. Its infestation arrests the growth of mycelium of button and oyster mushrooms due to scraping the spawn grain and cutting of mycelial strands. It produces pits on sporophores of all types of mushrooms which turn brown. In oyster mushrooms its damage results in withering of young sporophores. *Lepidocyrtus cyaneus* is known to infest mushrooms in Delhi, H.P. and Rajasthan.

Family ISOTOMIDAE

Lack trochanteral organ and scales, mucro short, postantennal organ present. *Isotoma.*

Family ONCOPODURIDAE

Have scales and long mucro; vesicular sense organs present on fourth antennal segment; postantennal organ present. Example: *Oncopodura.*

Family TOMOCERIDAE

Vesicular sense organs on fourth antennal segment absent; postantennal organ lacking. *Tomocerus.*

Suborder SYMPHYPLEONA

Head typically hypognathous; body subspherical or globose; indistinct or obsolete segmentation due to fusion of thoracic and first four abdominal segments

Family NEELIDAE

Antennae shorter than head. Example: *Neelus.*

Family SMINTHURIDAE

Antennae longer than head. Example: *Sminthurus, Bourletiella*

The life-history of *Sminthurus viridis*, a serious pest of leguminous plants, has been more fully studied. The insect is oviparous and a female lays as many as 120 eggs in a group on the ground and the young ones hatch in about three weeks. In about a month and a half, after undergoing six to eight moults it reaches maturity and hence ametabolous with post-adult ecdyses. Under favourable conditions there may be five generations in a year.

Family DICYRTOMIDAE

Antennae elbowed between the 2^{nd} and 3^{rd} segments. Example: *Dicyrtoma.*

◆ Chapter 43

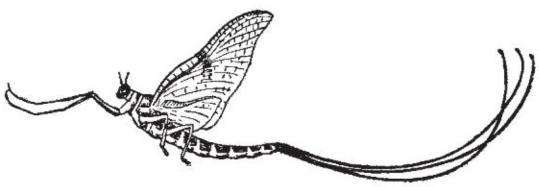
EXOPTERYGOTE INSECTS

Order Ephemeroptera

MAYFLIES

Mayflies or ephemerids are small to comparatively long (less than 1 cm), delicate, slender insects often found in the vicinity of streams, ponds and lakes. Most of the adults live for a few hours only and rarely several days and hence the name Ephemerida for the insects. The head of the adult mayfly is free, prognathous and possesses a pair of short antennae having a basal segment and multiarticulate setaceous filament (Fig. 43.1). The compound eyes are conspicuous and especially in males they are larger having largest facets on the upper portion. In some (Baetidae) the upper divisions of the compound eyes are mounted on a pedestal on the top of the head which are presumably used by the males for locating the female during the mating flight. The ocelli are three in number situated between the compound eyes. The mouthparts are atrophied and hence the adults do not feed.

The mesothorax is well developed and the pro- and metathorax are comparatively small. The wings are fragile, triangular and fan-like or corrugated providing them greater rigidity. Intercalary or accessory veins which are a characteristic feature of the mayflies are present in between the forked branches of the main veins. They are short



▲ **Fig. 43.1** *Adult mayfly*

longitudinal veins found near the margin having no basal connections but are connected to the main veins by cross-veins. Wing venation is of the primitive type and has considerable taxonomic importance in mayflies. All the main veins are represented including the anterior and posterior divisions of media in both pairs of wings, and R_5 is attached basally to anterior media (MA). The forewings are larger than hindwings. The hindwings are largest in the family Siphlonuridae and in others they may be very much reduced or even wanting as in *Cloeon* and *Caenis.* The wings are never folded but held vertically at rest. The legs are weak and are not used for walking; but in males they are elongated enabling to grip the females from below in their nuptial flight. Tarsi are five-segmented, but in more specialised forms one or two of the basal segments may be found fused with the tibia and in degenerated legs tarsi may be one- or two-segmented only. Tarsi end in a pair of claws, one being commonly degenerate or blunt.

The abdomen is slender and is composed of ten segments, the very much reduced eleventh segment being fused with it, and its tergite reduced or elongated as a median caudal filament. The abdominal segment ends in a pair of very long multi-segmented cerci either with or without a similar median caudal prolongation. It is quite probable that these may be concerned with the aerodynamics of flight in addition to any sensory function they might have. The female genitalia is without a conspicuous ovipositor but are represented by a pair of separate apertures, denoting the openings of the two oviducts situated between the seventh and eighth sterna. However, in some belonging to the family Leptophlebiidae a functional ovipositor is present. In the male the external genitalia are found on the posterior margin of the ninth sternum composing of a pair of claspers, having in between, a pair of penes more or less fused basally.

Naiads

The naiads (Fig. 43.2) or the aquatic nymphs, contrary to the adults, have a long nymphal life lasting even three years and show varied adaptation for the different kinds of aquatic environment. The naiads of mayflies inhabit clean water and some burrow in mud for which they have fossorial legs. Some species inhabit swift or torrential streams and have flattened body enabling it to cling to submerged stones.

▲ **Fig. 43.2** *Naiad of a mayfly*

A species in East Africa is known to live in wood burrows. The naiads are essentially herbivorous and feed on rich algal slime found on the surface of submerged stones. Rarely, some are known to be partly or occasionally predaceous. The naiads have well-developed compound eyes and ocelli and a pair of small conspicuous antennae. The mouthparts are of the biting type, with each of the mandibles having a single articulation with the head. The maxilla has a single lobe with two- to four-segmented palp. In the labium the ligula is conspicuously four-lobed with three-segmented palpi. The abdomen is provided with filamentous or plate-like abdominal gills being seven pairs in most species and is terminated by three caudal filaments. In *Cloeon* and *Siphlonurus* the three caudal filaments are fringed with setae and function as a kind of tail. In *Prosopistoma* the caudal filaments are fan-like and are used for swimming rapidly. The flattened gills arise dorsally and they are traversed by tracheae and hence some homologised them with wings. A few others from a study of their musculature and development, regarded them as abdominal appendages adapted for respiratory needs.

Metamorphosis is incomplete or hemimetabolous. The males swarm in large numbers and the females enter the swarm. During the nuptial flight the male approaches the female from below and copulation lasts for a few minutes only in flight. Several hundreds or up to about 4,000 eggs are laid by a female on water in clusters at a time or may be laid in smaller numbers beneath stones in water by alighting on the water surface or descending beneath water after which they float up again and fly away to repeat the process or may even die. In *Cloeon* and *Callibaetis* sp. ovoviviparity has been observed. In one to three years the naiad moults as many as 24 times before maturity.

Just before the emergence of the adult the naiad floats to the surface of water. A fissure appears on the dorsal surface and the winged mayfly called subimago issues out and in a few seconds it flies away. This winged insect has dull, opaque and usually fringed wings with cerci and legs not fully developed, and the closely set fine hair on its body makes it water proof, preventing it from getting bogged down. It flies to some distance, settles down and from a few hours to a few days again moults leaving behind the cast skin of a full-sized winged insect. The extra-winged stage is referred to as subimago and it is quite interesting and unique that no other winged insect moults after becoming a winged adult. This is considered to be a primitive feature in mayflies. The other remarkable primitive feature is possession of elongate cerci and the median caudal filament as found in the thysanurans.

About 1,500 species have been described so far. Relatively few species belonging to the genera *Cloeon*, *Ephemera*, *Potamanthus* and *Ecdyonurus* are known to exist on the North-West Himalayas in India. Ephemerids are useful in maintaining biotic balance in fresh water as they feed on plants and they also form a major item in the diet of other insects and of many fishes.

The ancestral mayflies that have been noticed in Carboniferous fossils show great reduction of the hindwings and typical species have been found in the lower Permian beds of Kansas and Russia.

The following five superfamilies and 19 families are recognised.

SUPERFAMILY 1. HEPTAGENIOIDEA

1. Family SIPHLONURIDAE

Wing venation copious; Cu1 with curved cross veins joining it posteriorly to the wing margin; eyes in males divided; Examples: *Siphlonurus, Ameletus.*

2. Family SIPHLAENIGMATIDAE – e.g. *Siphlaenigma janae.*

3. Family BAETIDAE

Reduced wing venation; hind wing reduced or absent; eyes in males turbinate; 3 tarsal segments in hindlegs; Nymphs with 6-7 pairs lamellate gills; Examples: *Baetis, Cloeon, Callibaetis, Centroptilum.*

4. Family OLIGONEURIDAE

Large triangular forewings; venation reduced; gills in nymphs simple; Examples: *Oligoneuriella.*

5. Family HEPTAGENIIDAE

Eyes in males undivided; 5 tarsal segments in hind legs; Nymphs flattened; gills lamellate and tufted; *Rhithrogena, Heptagenia, Ecdyonurus.*

6. Family AMETROPODIDAE

Nymphs subcylindrical; mid and hind leg claws long; Examples: *Ametropus.*

SUPERFAMILY 2. LEPTOPHLEBIOIDEA

Fore legs long, hind legs with 4 tarsal segments; eyes in males divided; three tail filaments.

7. Family LEPTOPHLEBIIDAE

Nymphs possess 5-7 lamellate or plumose gills; Examples: *Leptophlebia, Paraleptophlebia, Habrophlebia.*

8. Family EPHEMERELLIDAE

Robust nymphs with dorsal rows of spines or tubercles; Examples: *Ephemerella.*

9. Family TRICORYTHIDAE

Hind wings absent; Nymphs some times with concealed gills.

SUPERFAMILY 3. EPHEMEROIDEA

Venation copious; 4 tarsal segments in hindlegs; Nymphs burrowing, mandibular processes long; gills plumose.

10. Family BEHNINGIIDAE – e.g. *Behningia.*

11. Family POTAMANTHIDAE – e.g. *Potamanthus luteus.*

12. Family EUTHYPLOCIIDAE

13. Family EPHEMERIDAE – e.g. *Ephemera, Hexagenia.*

14. Family POLYMITARCIDAE – e.g. *Campsurus.*

15. Family PALINGENIIDAE – e.g. *Palingenia longicauda.*

SUPERFAMILY 4. CAENOIDEA

Nymphs specialized; gills absent on first abdominal segment; gills of second segment offer a protective operculum concealing the posterior gills.

16. Family NEOEPHEMERIDAE

17. Family CAENIDAE – *e.g. Caenis, Brachycerus.*

SUPERFAMILY 5. PROSOPISTOMATOIDEA

Nymphs characterised by extension of mesonotum covering thorax and half or more of abdomen.

18. Family BAETISCIDAE – *e.g. Baetisca.*

19. Family PROSOPISTOMATIDAE – *e.g. Prosopistoma.*

◆ Chapter 44

Order Odonata

DRAGONFLIES, DAMSELFLIES

ODONATA are brilliantly coloured, predaceous, medium sized to large insects with two subequal pairs of membranous wings and commonly called the dragonflies, damselflies and darning needles. They usually fly by day, particularly on a sunny day and a few are known to be active at night. The adults are aerial, but the nymphs are aquatic and are also predaceous like the adults. They feed voraciously on winged insects like mosquitoes, midges, gnats, flies, certain beetles, hymenopteran insects, etc. They capture their prey on the wing, scoop them out of the air with their bristly forelegs which form a kind of basket when held under the thorax. The insects are slender or stout-bodied, either cylindrical or flattened, and many are strong fliers or swift on the wing as can be seen from the fact that *Austrophlebia* can fly at a speed of nearly 100 km per hour. It may also be interesting that the female of *Megaloprepus coerulatus* measures about 190 mm across the wings. The adults are brilliantly coloured, and show varied colouration, and in many species even the wings are exquisitely coloured.

Adult

The adult odonate (Fig. 44.1) has a hypognathous, exceptionally mobile head, attached to the thorax by a slender neck. A pair of greatly developed compound eyes and three ocelli are present. The antennae are short, minute and 3- to 7-segmented. The mouthparts are of the biting type, ectognathous and the mandibles are strongly toothed. The maxilla has a single-lobed dentate mala representing the fused galea and lacinia, and an unsegmented palpus. In the labium the prementum represents the squamae or expanded pieces on either side, each carrying a lateral lobe terminating towards the inner border in an endhook and externally in a small moveable hook; the whole structure is probably the modified two-segmented labial palp. In between the lateral lobes is present the ligula which is often medianly cleft. The prothorax is much reduced, small and distinct whereas the meso- and metathorax are intimately fused together. The pleurites of these segments are very well developed and slant steeply backward resulting in the terga and wings being shifted posteriorly and the sterna being moved far forward with the legs close to the mouth. The legs are short, spiny and unfit for walking and have three segmented tarsi ending in a pair of claws and rudimentary empodium. The wings are long, transparent and net-veined having a large number of cells with characteristic pterostigma (thickening of the wing-membrane between C and R) which may be absent in a few cases. Vein Sc ends in a conspicuous nodus or incision near the middle of the costal margin. The fore- and hindwings may be equal and held vertically at rest or basally the hindwings may be broader and held horizontal at rest. The wing venation is of considerable taxonomic importance in Odonata.

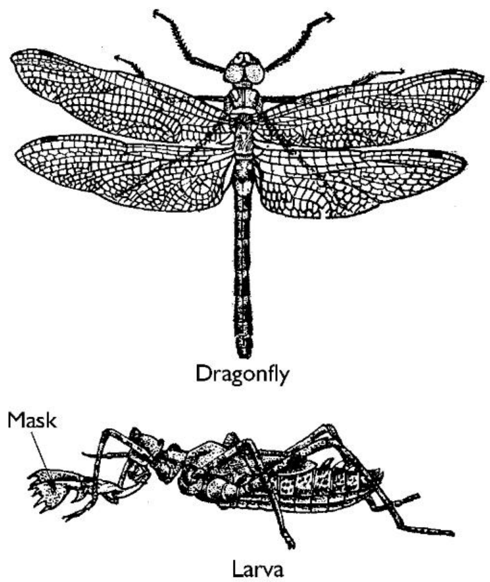


Fig. 44.1 *Dragonfly—adult and naiad*

In the slender abdomen ten segments are distinct and the vestigial eleventh segment in the male forms the supra-anal plate. A pair of superior anal appendages of secondary structures are borne posteriorly on the tenth segment in the male but reduced or vestigial in the female. The tergite of the eleventh segment in Anisoptera males is produced into median inferior anal appendage, which is rudimentary in other cases. In male Zygoptera the paired cerci represent the paired inferior anal appendages which are short and unsegmented. Surrounding the arms are a median dorsal lamina supra-analis and paired lateroventral laminae infra-anales. During pairing the male grasps the female by means of its anal appendages in the region of the neck in Anisoptera or the prothorax in Zygoptera. The true genital aperture opens on the ninth segment. The male copulatory organs developed from the second and third abdominal sterna, are found in a depression or genital fossa on the second sternum, which is a unique feature among insects. From the anterior region of the third sternum is a vesicle from which arises the penis and associated with it are a pair of claspers or hamuli. In the female the ovipositor is made up of three pairs of appendages, viz. an anterior pair from the eighth abdominal segment and an inner pair and a lateral pair of valves from the ninth abdominal segment. This type of ovipositor is seen in Zygoptera and in Aeshnidae and Petaluridae among Anisoptera but among others either the lateral valves alone are vestigial or all three pairs are vestigial or absent.

The odonates are oviparous. Oviposition may be exophytic in which the eggs are freely dropped into water attached superficially to aquatic plants (as in most Anisoptera) or endophytic in which the eggs are inserted into the stem and leaves of plants or other objects near or beneath water (as in Zygoptera or in the families Aeshnidae and Petaluridae of Anisoptera). The newly hatched nymph is the pronymph.

Naiad

The nymphs of Odonata are aquatic (naiad) and campodieform. In the naiad of dragonflies (Anisoptera) the body is terminated by three small process, viz. a median appendix dorsalis and a pair of lateral cerci. In these forms respiration is by means of concealed rectal tracheal gills, i.e. water is taken in through the anus and is then forced out. In the damselflies (Zygoptera) the terminal processes are well developed and form caudal gills which function much like the tail of a fish. Almost all the nymphs are aquatic and may live in fresh water or sand or mud. They are predaceous and feed on nymphs of Ephemeroptera, culicid larvae and nymphs of their own kind and other species. The life cycle or the nymphal period may last for a year as in most Zygoptera or may occupy two years or even three to five years in others. Between egg to imago there are about 10 to 15 instars.

In the naiad the labium is modified for prehensile purposes and is known as mask. It comprises markedly lengthened prementum and postmentum and a median undivided ligula fused with the prementum. The labial palpi comprise of lateral lobes each carrying on its outside a movable hood. At rest, the postmentum is reflexed between the bases of the legs with the prementum hinged upon it ventrally. The mask is used exclusively for capturing prey. It is thrown forward and extended with lightning rapidity and the prey is seized on the movable hooks. The respiratory system is highly specialised in the nymphs, particularly in Anisoptera or dragonflies where the tracheal gills form an elaborate branchial basket. In most Zygoptera, caudal gills are present and only rarely are lateral abdominal gills present. Spiracles are present only in the meso- and metanota, but the metathoracic and abdominal spiracles are nonfunctional generally. In the branchial basket, the anterior part of the rectum forms the gill chamber and the gills are developed as six long folds of the rectal wall. Water is taken into the rectum and expelled forcibly. There are obliquely placed gills overlapping each other (implicate type) or leaf-like (foliate) or as flat plates (lamellate).

When fully grown, the nymph ceases to feed and when the internal changes are complete it comes out of water and fixes itself to a stationary object. Along the middorsal line of the thorax the cuticle splits and the imago then withdraws its head and thorax and finally the abdomen. It rests until the wings and abdomen are fully extended.

It is believed that the ancestral Odonata existed in the Carboniferous period as could be seen from the fossils discovered in France. They had a wing spread of more than two feet and were less specialised than living forms. Fossils found in Kansas Permian strata represent the typical Odonata.

Odonata comprises three suborders and majority of them belong to two suborders, viz. Anisoptera (dragonflies) and Zygoptera (damselflies). Following are the characters by which they can be easily distinguished both in the adult and nymphal stages.

	ANISOPTERA (dragonflies)	*ZYGOPTERA* (damselflies)
Adult		
1.	Eyes meet middorsally in many and occupy largest part of head	Eyes much smaller, do not meet and button-like
2.	Occiput, vertex and frons are distinct sclerites	The sutures are less distinct or absent
3.	The hindwings are broader basally and held horizontally, are depressed at rest	Identical and held vertically at rest
4.	Strong fliers	Weak fliers

(Contd.)

	ANISOPTERA **(dragonflies)**	*ZYGOPTERA* **(damselflies)**
5.	Labium with middle lobe deeply cleft	Labium variable
6.	Male possesses two superior and one inferior anal appendages; penis jointed	Male possesses two superior and two inferior anal appendages; penis not distinctly joined
7.	Ovipositor normal or atrophied	Ovipositor complete
8.	Oviposition exophytic	Oviposition endophytic
Naiad		
1.	Large and robust with rectal gills and anus covered by a median dorsal appendage and two cerci	Small and slender with the three caudal gills

The third suborder Anisozygoptera is represented only by a few species from Japan and India and combines the characteristics of the other two suborders. Imago has the body form of Anisoptera and venation of Zygoptera. Naiad closely resembles that of Anisoptera.

Suborder ZYGOPTERA

Wings are petiolate basally, with both wings almost subequal in form and venation. Eyes protruding laterally, well separated. Labium with a deep cleft on middle lobe. Nodus placed before middle of wing. Nymphs with three caudal gills and slender, elongate abdomen; gizzard with 5 to 16 folds.

This suborder is represented by four superfamilies viz., Coenagrioidea, Hemiphlebioidea, Lestinoidea and Agrioidea The superfamily Coenagrioidea consists of six families viz., Platystictidae, Protoneuridae, Platycnemidae, Coenagriidae, Pseudostigmatidae and Megapodagriidae. The superfamily Hemiphlebioidea consists of a single family Hemiphlebiidae. The superfamily Lestinoidea consists of three families viz., Perlestidae, Chlorolestidae and Lestidae. The superfamily Agrioidea consists of seven families viz., Pseudolestidae, Amphipterygidae, Chlorocyphidae, Heliocharitidae, Polythoridae, Epallagidae and Agariidae.

Suborder ANISOZYGOPTERA

Mostly fossil species and living ones include two species from Japan and India. Adult has a zygopteran venation but the general form of the body is anisopterous and the nymphs resemble Anisoptera. E.g. *Epiophlebia*.

Suborder ANISOPTERA

Without petiolate fore- and hindwings, with the latter more broadened at base. The discoidal cell of forewing differentiated into a triangular and supertriangular areas. Eyes large, mostly contiguous. Wings held horizontal or depressed in repose. Larvae with rectal gills and with four to eight folds in gizzard. Penis jointed.

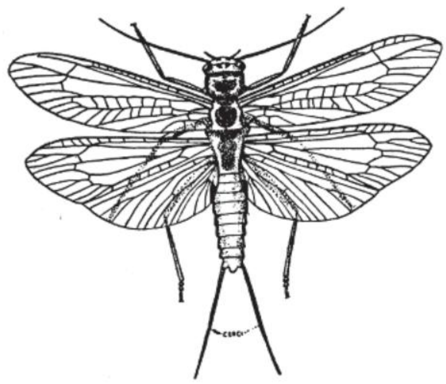
There are three superfamilies: Aeshnoidea, Cordulegasteroidea and Libelluloidea. The superfamily Aeshnoidea comprises the families Gomphidae, Petaluridae and Aeshnidae. The superfamily Cordulegasteroidea consist of a single family Cordulegasteridae. The superfamily Libelluloidea consists of the families Synthemidae, Corduliidae, Macrodiplactidae and Libellulidae.

◆ Chapter 45

Order Plecoptera

STONEFLIES, SALMONFLIES AND PERLIDS

THE STONEFLIES are soft-bodied insects, moderate to large in size and abundant, especially in the vicinity of rapid streams and lakes. They are predominantly of grey, black, brown or green colour and are poor fliers. They are commonly referred to as stoneflies in view of the fact that the nymphs are exclusively aquatic, found in abundance under stones in cold and well aerated fresh water torrential streams on mountains. Unlike the mayflies, the stoneflies are seldom found in the plains but they are abundant in streams immediately below the permanent snow and ice on the mountains. The adult stonefly is elongate and depressed with nearly parallel sides (Fig. 45.1). The head is prognathous with weak biting type of mouthparts and long many-segmented setaceous antennae. Compound eyes and three ocelli (rarely two) are present. The mouthparts are generally poorly developed and apparently some do not feed. However, some species in which the mandibles are well developed are known to feed on buds and leaves or nibble on algae encrusting rocks and trees. The maxillary palpi are five-segmented and the labial palpi three-segmented.



▲ **Fig. 45.1** *Stonefly* Perla *–adult female* (from B.D. Moreton)

The prothorax is large and free and the meso-and metathorax are subequal. The two pairs of wings are membranous, usually with many veins and numerous cross-veins, the hindwing being larger than the forewing. A wing coupling apparatus is lacking and the hindwings are folded in plaits over the abdomen when in repose. A few are known to be wingless. Sexual dimorphism is also well known in stoneflies. In some the males are short-winged, e.g. *Perla cephalotes*, and in others such as *Capnia gibbera* and *C. bifida* which occur on the southern slope of the Himalayas, males are apterous. The legs are strong with three-segmented tarsi each ending in a pair of claws and an empodium.

The abdomen is 10-segmented with vestiges of an eleventh segment. The female opening is found on or behind the eighth abdominal sternum and an ovipositor is wanting. In the male the opening is found behind the ninth sternum and a copulatory organ is lacking. Usually a pair of long multi-segmented cerci are present, but in some they are short and single-segmented and a few bear a rudimentary second segment also and these are used in copulation. A drumming sound is produced by the males of some species which have a disclike percussion hammer on the ninth abdominal segment for that purpose. There are two pairs of thoracic and eight pairs of abdominal spiracles.

The Naiad

The nymphs are essentially and exclusively aquatic found in cold and well aerated fresh water on the mountains. The head is prognathous with a pair of multi-segmented antennae, a pair of compound eyes and three ocelli. The mouthparts are of the biting type and the naiads in most species are phytophagous and feed on the algal slime on submerged stones. They have large mandibles with a prostheca, stout maxillae and long glossae. Many are predaceous on chironomid and deuterophlebiid larvae, Hydracarina and on naiads of mayflies. Such carnivorous forms have a slender mandible without a prostheca, weak maxillae and reduced glossae. Some are omnivorous.

The tracheal system is apneustic and respiration is either branchial or cutaneous. In the primitive type of nymphs belonging to the family Eustheniidae five to six pairs of gills are present as lateral abdominal appendages, whereas in others secondary tracheal gills occur on various parts of the body such as submentum, neck, thorax, coxae, the first two or three abdominal segments or the anal region. The gills may be filamentous or single or arranged in tufts. The naiads of the species that belong to the genera *Isoperla, Leuctra* and *Capnia* do not possess gills. It is quite interesting that the branchiae in a shrivelled, non-functional condition may persist in the adults.

The gonads are multilobular, and the ovary is with numerous ovarioles. Just before emergence of adult, the naiad moves out of the water and crawls on land. There is no nuptial flight but mating occurs on the ground by the male mounting on the female and curving the abdomen to one side of the female. The eggs are discharged into the water in several masses over a period extending up to three weeks and the female may lay several hundreds to several thousands of eggs. As soon as the egg mass is deposited, the sticky slime by which the eggs are held together dissolves in water and the eggs separate. The eggs may be spherical or tetrahedral or ovoidal.

The naiads which hatch out from the eggs in one or two months cling to the underside of stones. The developmental period varies from one year in smaller forms, to four years in larger forms. The naiad during its development moults a number of times and as many as 33 ecdyses have been reported in *Perla cephalotes* over a period of three years. Ovoviviparity has been reported in some species like *Allocapnia vivipara* and *Capnia nigra*.

Most of the stoneflies show reference for low temperatures as the naiads mature quickly and emerge as adults in cold weather but in such species very little development occurs during the summer.

The naiads are sometimes fed upon by freshwater fishes. The stoneflies are used by the anglers as a bait for trout. On the Himalayas the naiads are hunted by the Himalayan dipper and the dead adults are eaten away by swarms of Collembola, Carabidae, Staphylinidae, Diptera and birds like chough. In general they are of little economic importance.

Over 1,500 species are known so far. In the North-West Himalayas at an elevation of 4,000 metres the stonefly *Rhabdiopteryx lunata* is commonly noticed.

Stonefly-like insects having short wing-like lobes on the pronotum are represented in the extinct order Protoperlaria of Kansas. It is believed that the immature forms of these were aquatic with swimming legs and several pairs of abdominal, lateral tracheal gills. The species which come under the family Eustheniidae are like the extinct forms among the existing forms of stoneflies. It is also believed that the existing forms might have appeared during the Jurassic period.

The following suborders and families are recognised.

Suborder 1. ARCHIPERLARIA

Primitive, coloured, wings with abundant cross veins; glossae and paraglossae almost equal in size, maxillary palpi filiform; nymphs with paired lateral gills on first four to six abdominal segments. It comprises of two families viz., Eustheniidae and Diamphipnoidae.

Suborder 2. FILIPALPIA

Reduced cross veins; nymphs without segmentally arranged gills. It comprises of two superfamilies viz., Leptoperloidea and Nemouroidea. The superfamily Leptoperloidea consists of the families Austroperlidae, Scopuridae, Peltoperlidae and Gripopterygidae. The superfamily Nemouroidea consists of the families Taeniopterygidae, Leuctridae, Capniidae and Nemouridae.

Suborder 3. SETIPALPIA

Maxillary palpi subuliform with weakly developed mandibles; nymphs do not possess segmentally arranged abdominal gills. It comprises of two superfamilies Pteronarcoidea and Perloidea. Pteronarcoidea is represented by a single family Pteronarcidae which has the Giant Stonefly of N. America *Pteronarcys dorsata* which measures up to 60 mm long. Perloidea consists of the families Perlidae, Perlodidae and Chloroperlidae.

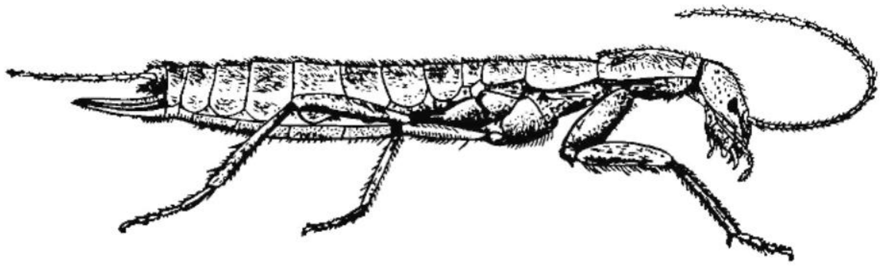
◆ Chapter 46

Order Grylloblattodea

The members of this order are medium-sized light-coloured insects and are found beneath stones, at altitudes of 500–2200 m. They prefer a characteristically cold environment and are found active at the margins of melting snow fields and ice caves. They are nocturnal and omnivorous and they feed on vegetable material and dead insects. The first representative, *Grylloblatta campodeiformis*, was discovered in 1914 by Walker in the Canadian Rockies who placed it tentatively under Orthoptera.

The head of the insect is prognathous and flattened with a complete tentorium. The compound eyes are either absent or reduced to group of about 60 ommatidia on each side. Ocelli are absent. Antennae are long, filiform and multisegmented. Mouthparts are of the biting type and ectognathous, and comprise of a pair of mandibles, a pair of maxillae with five-segmented palpi, without palpifer and the labium in which the prementum bears a pair of three-segment palpi. Hypopharynx is present.

The insects are secondarily apterous. The legs are slender with five-segmented tarsi having ventral pads and a pair of claws. Coxae are large without mera. Arolium and pulvilli are wanting. Abdomen possesses ten distinct segments, the eleventh being vestigial. The female possesses an exserted sword-like ovipositor. The anterior pair of valves of the ovipositor is derived from the somewhat reduced eighth sternite and the remaining two pairs of valves form the greatly reduced ninth sternite. The male genitalia are asymmetrical and the coxites of the ninth sternite bear the two terminal styles. Cerci are long and eight segmented and are present in both the sexes.



▲ **Fig. 46.1** *Grylloblatta campodeiformes (after H.M. Lefroy, Textbook on Agricultural Entomology, H.S. Pruthi, 1969).*

The insect is oviparous and a year old female lays black eggs singly in soil or moss. Incubation period is about a year. There are eight or more instars and in about five years maturity is reached. There is only one family Grylloblattidae and *Grylloblatta* being the well defined genus. About 20 species are known from the mountains of Western North America, Russia and Japan. Fossils are known. The members of this order are very interesting as they form the remnants of the primitive orthopteran stock from which the crickets and the roaches were derived. The legs with large cerci and asymmetrical male genitalia are primitive and show blattoid affinities. At the same time, presence of tentorium, absence of meron and well developed ovipositor show orthopteran affinities. The characters like reduced eyes, absence of ocelli, and the hypopharynx preclude being directly ancestral to any of the other orthopteroid orders.

◆ Chapter 47

Order Orthoptera

GRASSHOPPERS, LOCUSTS AND CRICKET

The Orthoptera comprise medium to large sized, active, mostly terrestrial insects and include the well known grasshoppers, locusts, crickets, mole crickets etc. They are well represented in the tropics and some like the locusts are capable of sustained flight and are known to be very destructive to crops and vegetation. They are mostly phytophagous, but a few species are predaceous and the others omnivorous.

The head is generally hypognathous, rarely prognathous, bearing a pair of usually large compound eyes. Normally three ocelli are distinct, but absent in the wingless species or reduced to two in some long-horned grasshoppers. Most of the sutures and sclerites characteristic of blattids are distinct, though the epicranial suture is not always well developed. The tentorium is X-shaped and distinct. The antennae are long and filiform in tettigonids, but shorter and more moniliform in the short horned grasshoppers. The mouthparts are ectognathous, mandibulate, with strong grinding edges in the phytophagous forms and more elongate and pointed in the omnivorous and carnivorous species. The apically bidentate laciniae and the five-segmented palps are characteristic of the maxillae, while the labium consisting of the usual three plates, bears the three-segmented palpi, paraglossae and reduced glossae.

The large notum of the prothorax covers the major part of the thorax and the meso- and metathorax are comparatively much shorter. In many the legs are unequally developed, the hind pair of legs being typically adapted for jumping. In the mole crickets the hindlegs are normal, but the forelegs are fossorial, the tibiae having large teeth for this purpose. The tarsi may be one or two-segmented in the Tridactyloidea, three-segmented in the gryllids and acridids, four in the tettigonids or rarely five-segmented. There are two pairs of wings, the forewings narrow and thickened into the protective tegmina. The hindwings are membranous, with a large anal area, folded fanwise under the forewings while at rest. The macropterous and brachypterous forms are noticed in both sexes, while in others, the females alone may be brachypterous. In the males of tettigonids and gryllids the cubito-anal areas show modifications for stridulation.

The abdomen is usually 11-segmented. The external genitalia of the female consists of a well developed ovipositor, derived from a pair of ventral valves from the eighth abdominal segment and two pairs of inner dorsal valves from the ninth. In the gryllids the ovipositor is long and needle-like, but an ovipositor is wanting in the gryllotalpids. In acridids the ovipositor is short and stout for boring into the soil or rarely into plant tissues for oviposition. In the male the ninth abdominal sternum is enlarged and conceals the genitalia. The anal cerci are unsegmented and short.

Stridulation and sound production are unique in Orthoptera. Mostly the males stridulate, but the females of some species can also produce sound. The organs concerned are alary and femoro-alary, the former met with in the tettigoniids and gryllids and the latter in most acridids. In some acridids the stridulatory files are seen even in the first instar nymph and consists of minute tubercles or pegs running from the base of the femora to the apex. In the adult the tubercles are well developed and form into distinct pegs becoming closely packed medially and each peg lies in an individual socket. The sexes are brought together by this process of stridulation. Auditory organs also occur in both sexes. In the acridids a pair of tympanal organs are noticed one on either side of the first abdominal segment. In tettigoniids and gryllids they are situated near the proximal end of each foretibia.

The alimentary canal generally bears a spacious crop, leading into a strong, sclerotised gizzard in the tettigoniids and weakly developed in the acridids. The cuticular armature of the foregut is strongly developed in the acridids and is specialised in accordance with the type of plants used. There are six gastric caeca in the acridids and only two in the tettigoniids and gryllids. The numerous malpighian tubules open independently into the gut in the acridids, in groups in the tettigoniids or as in the gryllids unite to form a common duct. Six rectal papillae are characteristic of the hindgut. The salivary glands are poorly developed in the acridids and lack a reservoir, but well developed in tettigoniids. The nervous and respiratory systems are as in most blattids, but the acridids possess segmentally arranged air sacs. The testes are compact bodies with numerous follicles enclosed in a sheath, while the ovaries made up of numerous panoistic ovarioles may be arranged lateral to the oviducts or in a cluster.

The members of this order are oviparous and parthenogenesis is rare. Copulation takes place in different ways in the various species. The eggs may be laid in or on the ground as in almost all Acridoidea, most Gryllidae and some Stenopelmatidae or in plant tissues as in many Tettigoniidae and some others. The eggs may be laid separately or may be enclosed in a cylindrical 'pod' as in Acridoidea. There are generally four to six instars but exceptionally in *Gryllus campestris* up to ten moults have been observed. In general the life-cycle occupies a year but in some two broods a year are noticed. In wingless forms metamorphosis is slight as evidenced by increase in size and differentiation of appendages and genital segments. In winged forms the wing pads arise in the third instar and the hindwings are over the forewings. The hindwings get unravelled into normal position at the last moult. This type of reversal of wing pads is found in the order Odonata also.

SUBORDER ENSIFERA

Antennae longer, many segmented, tympanal organs when present are on the foretibiae.

SUPERFAMILY TETTIGONOIDEA

Tarsi four-segmented; long-horned grasshoppers

Family Tettigoniidae (Long-horned Grasshoppers, Katydids)

They are recognised by long setaceous antennae, the four-segmented tarsi and the tympanal organs on foretibiae (if present). Wingless forms are common and mostly live nearer the ground. In winged forms the left tegmen over laps the right one. The cubitoanal region of the tegmina are modified asymmetrically for stridulation in male. The stridulatory vein (A1) on the left tegmen bears a row of teeth or 'file' which is scraped by the right tegmen at the time of stridulation. Winged forms are mostly green. The ovipositor is sword-shaped laterally flattened and very long, sometimes exceeding even the length of the body. The eggs are thrust into plant tissue in neat longitudinal rows and some laid in the soil. Predominantly they are herbivorous but some may be carnivorous and others omnivorous. Protective resemblance is well exhibited in the long-horned grasshopper *Sathropyhyllia* sp., commonly found in South India.

Family Schizodactylidae

Burrowing forms; *Schizodactylus monstrosus* is a large Indian species with coiled tegmina.

Family Gryllacrididae—*Wingless forms*

Family Stenopelmatidae

▲ **Fig. 47.1** *Schizodactylus monstrosus (T. B. Fletcher, 'Some South Indian Insects' 1914)*

Also wingless forms and hiding in caves. Both these groups are poorly known in India.

Family Phasmodidae

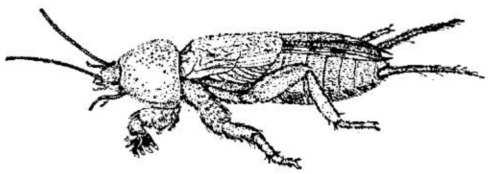
Wingless forms with long, slender bodies looking like stick insects.

SUPERFAMILY GRYLLOIDEA

Tarsi three-segmented; crickets and mole crickets.

Family Gryllotalpidae (Mole crickets)

They are usually brownish and possess short antennae and two or three-segmented tarsi. They are subterranean in habit, with very broad and spade-like toothed forelegs, resembling the forepaw of a mole, modified for digging. The eyes are reduced and the ovipositor is vestigial. The forewings are short and at rest the hindwings are folded over the abdomen. A humming sound is produced by the vibration of the wings, and they do not possess stridulatory organs. They are sometimes destructive to cultivated plants. The most common species is *Gryllotalpa africana* which has been known to cause serious damage to stored potatoes (Fig.47.2).



▲ **Fig. 47.2** *Gryllotalpa africana (mole cricket)*

Family GRYLLIDAE

Crickets possess long antennae and three segmented tarsi. Males stridulate by friction of similarly modified tegmina and the auditory organs are located on the foretibiae. Ovipositor is long, slender and needle-like. Cerci are extremely long and unsegmented. Mostly they are omnivorous. The house crickets *Gryllus* sp. are often a nuisance as they produce shrill chirping noise and bite holes in clothing. The cricket *Brachytrypes portentosus* forages on casuarina seedlings during night time.

Suborder CAELIFERA

Antennae shorter with less than 30 segments, and tympanal organs lies one on either side of the first abdominal segment.

SUPERFAMILY ACRIDOIDEA

Tarsi three-segmented; includes the locust and short-horned grasshoppers.

Family Acrididae (Short-horned Grasshoppers, Locusts)

Members of this family are often destructive and especially the locusts are very destructive to crops and vegetation. They are recognised by the short antennae, the three segmented tarsi, the auditory organs one on either side of the first abdominal segment and the short ovipositor. Stridulation is by means of rubbing the inner surface of the hind femur, which has a row of small peg-like spines, against lower edge of the front wing, or by rubbing the anterior edge of the hindwing against the posterior margin of the forewing. In the former case a low buzzing sound is produced and in the latter case a sort of crackling sound is produced. The short ovipositor is used for excavating a hole in the ground and more rarely in plant tissue or decaying wood. Eggs are laid in groups of 30 to 100 or more and the fluid secreted around the eggs forms a hard covering or 'pod' which affords water proof protection.

Family Eumasicidae

Tropical group with pronotum usually flattened dorsally.

Family Pneumoridae

Males with abdomen inflated. Stridulatory ridges present on sides of second abdominal tergum.

Family Tetrigidae

Well defined group with pronotum extended backwards to cover abdomen, and tegmina reduced to small scales.

Family Proscopiidae

Mostly apterous, confined to South America. Body elongate, rod-like and legs long and thin.

SUPERFAMILY TRIDACTYLOIDEA

Tarsi one- or two-segmented.

Family Tridactylidae

Live near water burrowing into sandy areas. Very small forms with large hindfemora.

Family Cylindrachaetidae

Apterous, subterranean, burrowing forms with long cylindrical bodies and with fossorial legs. Hind femora not enlarged.

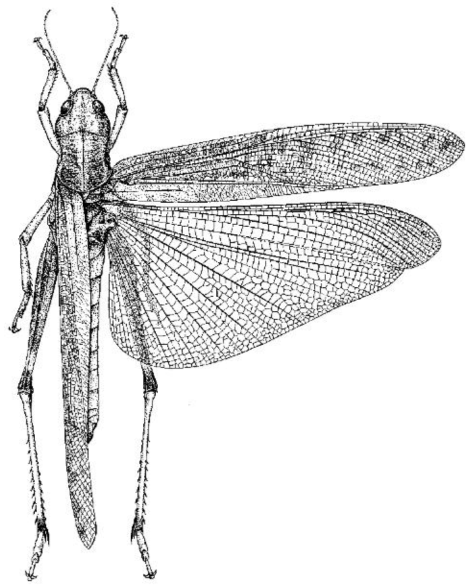
LOCUSTS

Locusts are grasshoppers which multiply enormously under certain favourable conditions, form swarms and migrate in millions from place to place or country to country feeding on all vegetation on their way. In the world nine species are well recognised as locusts. In India three species of locusts, viz. the Bombay locust (*Patanga succincta*), the migratory locust (*Locusta migratoria*) and the desert locust (*Schistocerca gregaria*) are found and the last one is the most destructive species.

The Bombay locust

It is distributed in India, Sri Lanka, Philippines, Indonesia, Malaysia, Thailand, Java, Sumatra, Borneo and China. In India generally it is restricted to the area extending from Gujarat in the north to Tamil Nadu (Chennai) in the south. It breeds in the Western Ghats and has one brood in a year. Grasshoppers are found scattered among crops or grasses and do not congregate. Its plagues occurred during 1835–45,1864–66 and 1901–08 and heavy damage was caused to crops. Since 1908, when the last plague of this locust came to an end, scattered individuals were found in the Rajasthan desert and the adjoining parts of Gujarat during autumn, winter and summer. Observations made during 1957–68 revealed that such scattered immigrant locusts commence reaching the desert area almost every autumn, the earliest find being towards the end of October. They generally concentrate among the tall growing sedge *Cyperus tuberosus* in Rajasthan. This locust was also found in the Laccadive islands during 1960-69, adults damaging coconut plantations and wild vegetation. Unlike Western Ghats and areas like Madhya Pradesh, where breeding occurred during monsoon (June-August), in these islands Grasshopper infestations occur during January-March (eggs are apparently laid in November-December).

There is only a single brood in a year, the duration of adult stage being nine months, i.e. there is a prolonged imaginal diapause. The impact of increasing photoperiod in reducing the diapause has been indicated. A single female may lay up to 4 egg pods, the total number of eggs being 606. The incubation and nymphal periods range from 30–40 and 42–111 days, respectively. The grasshoppers generally pass through seven instars, resulting in 8 eye-striped adults but sometimes 8 or 9 instars occur and the resultant adults have 9 or 10 eye-stripes. On fledging, the hindwings are transparent white, the rosy colour appears after 30–50 days. The pronotal stripes which are yellow on fledging, become white within 21–59 days. They again turn yellow within six months of fledging.



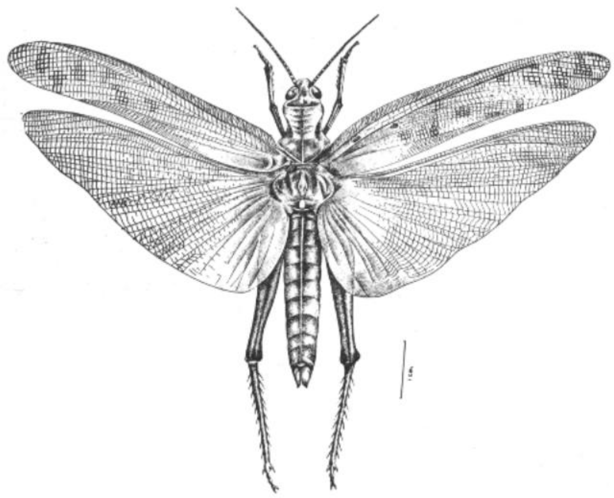
▲ **Fig 47.3** *MIGRATORY LOCUST Locusta migratoria (Linnaeus) dorsal view (Illustration by R. Kohout, Queensland Agricultural Journal, 1976)*

The migratory locust: (Fig. 47.3)

It is distributed in Europe, Africa, Pakistan, Eastern Asia and Australia. It is ordinarily found as scattered individuals but sometimes increases in numbers in some parts of India, especially in Gujarat, Rajasthan and South India where it causes damage to crops and pastures. Its swarm occurred in Tamil Nadu (Chennai) in 1878. There was heavy and concentrated breeding and swarm formation of this locust during February-March 1954 in the Ramanathapuram district of Tamil Nadu and this was attributed to the swarm observed over Bangalore in June 1954. In general the locust breeds in Baluchistan (Pakistan) during the spring and the resultant adults which migrate into the desert areas of India breed there during summer. Hoppers pass through five to six instars.

The Desert Locust: Fig. (47.4)

It invades about 30 million square kilometres area and in 50 per cent of the area breeding can occur. Invasion extends from West Africa to Assam. The area from west and north Africa, eastern Africa, Tanganyika, all countries of the Middle East up to Turkey, southern most Soviet Republic, Iran, Afghanistan, Pakistan and India, forms the invasion belt (Fig. 47.5). In India the swarms reach Assam in the east and Kerala in the south. Breeding takes place during summer (July–September) or during spring depending on the rains in the different areas and thus migrations are seasonal. In the eastern region desert locust invasion belt comprises Iran, Pakistan, Afghanistan and India. Breeding occurs in India and adjoining parts of Pakistan during the monsoon rains and the resultant swarms formed from August onwards migrate as far as west Iran and eastern Arabia. With the onset of rains during winter-spring in this area one or two broods occur and the resultant swarms migrate to Indo-Pakistan region during May–July.



▲ **Fig. 47.4** *The Desert Locust Schistocerca gregaria, Dorsal view (H.S. Pruthi, Textbook on Agricultural Entomology, ICAR, New Delhi, 1969)*

▲ **Fig. 47.5** *Desert locust swarms near Gigiga, Ethiopia (Courtesy: C. Ashall, and Antilocust Research Centre, London)*

Uvarov enunciated the theory that there are two phases in locusts differing structurally and biologically: the phasis solitaria or solitary phase and the gregarious phase or phasis gregaria. Intermediate forms or phasis transiens are also observed. The view that in the solitary phase they lead a solitary, sedentary life, with the individuals more dispersed, and that in the gregarious phase they are highly crowded, active, with dense population and that this is a reversible process, is not accepted today. Recent investigations have shown that the solitary individuals are more juvenile and that there is a greater influence of the corpus allatum hormone or juvenile hormone in the solitary than the gregarious forms throughout life. In other words, to be juvenile is to be more specialised for vegetative exploitation. Further the prothoracic glands do not disappear in the adult. The juvenile hormone and the neurosecretory cells in the brain act on the reproductive system at the same time. The gregarious forms on the other hand are more adult in terms of structure, physiology and behaviour. Visual, mechanical and chemical stimuli contribute towards the process of gregarisation. Diffusion of a specific substance from one sex promotes sexual maturity and which is also significant in communication between individuals in crowds. When suitable food, oviposition sites, etc. are available, there is a kind of an ecological opportunism resulting in a group effect.

In the solitary phase the nymphs are green, grey or brown and the adults have longer and crested pronotum and relatively longer hindfemur. In the gregarious phase the nymphs are black and yellow or orange and the adults have shorter and saddle-shaped pronotum and relatively shorter hindfemur. In the latter phase only the nymphs live in large bands and march from place to place during the warmer part of the day. The adults of the gregaria phase form large dense swarms which fly over great distances under the influence of winds and they settle when there is a fall in temperature.

During the recession period the adults of the solitaria phase breed in the desert or 'outbreak' areas, and extensive and intensive breeding may lead to transformation of solitary phase to gregaria phase and formation of incipient swarms. Generally during a series of years, i.e. 5 to 10 years, considerable numbers of swarms of plagues may be noticed which may be followed by a recession period of one to eight years during which the swarms originate in more or less permanent outbreak areas. Gregarisation must be prevented in these places for successful locust control.

Life History The male and female, adults mature in about 10 and 13 days respectively. After copulation, the female drills holes in moist sandy soil up to 8 to 10 cm and lays the eggs in a cluster and covers them by a frothy secretion making a waterproof plug. About 1000 egg pods per sq. metre may be noticed. A female lays eggs thrice in its lifetime at intervals of a week. Eggs hatch within two weeks (summer) or 3 to 4 weeks (spring) and the young grasshopers come to the soil surface. The pale coloured grasshoppers attain black colour soon and congregate into groups and begin to march as a band within 24 hours. After a few days they move to the vegetation and in the gregaria phase there are five nymphal instars. Nymphal period is about four weeks during summer and may be prolonged during autumn and spring. After the final moult they become adults and in about a week the fresh swarm thus formed moves out of the area.

Control Some of the control measures used against locusts are as follows:

- Spraying neem kernel suspension on valuable plants serves as deterrent to lo custs.
- The areas of egg layers are to be located and the eggs destroyed on an organised scale by ploughing, digging or harrowing.

- Trenches of about 45 cm deep and 30 cm wide are dug across the front of marching grasshoppers and the grasshoppers are driven to the trenches and destroyed. The trenches are generally provided with metal sheet barriers over which the grasshoppers cannot jump.
- Grasshoppers congregated on bushes are burnt by using flame throwers.
- Poison baits are cast in front of the moving bands of grasshoppers or in the grasshopper infested bushes. The baits are usually prepared by mixing wheat or rice bran with an insecticide and suitable attractants like molasses. The hoppers get killed when they feed on the bait.
- Aerial or ground application of ULV formulation of either malathion or fenitrothion has given effective control of locusts.
- For the control of swarms time factor is important since the resting period is very short and the operations have to be completed before morning when the swarms fly away.

Other well-known locusts are the Moroccan locust (*Dociostaurus moroccanus*), the brown African locust (*Locustana pardalina*), and the African red locust (*Nomadacris septemfasciata*).

For successful control of locusts moving from one country to another, international co-operation is essential. There is a convention between the Governments of India, Pakistan and Iran under which information regarding the locust situation is regularly exchanged and every year the representatives of these countries meet, review the situation and discuss plans for action. Since 1939 India has been maintaining a permanent locust warning organisation which keeps a careful watch over the fluctuations of locust populations in the desert outbreak areas. The organisation also collects information from the various states and countries and disseminates it to all concerned by means of periodical bulletins and radio broadcasts. The organisation works under the control of the Plant Protection Adviser to the Government of India, Directorate of Plant Protection, Quarantine and Storage, Ministry of Food and Agriculture, New Delhi. It may not be out of place in this connection to mention that pioneering work on locusts and their control in this country has been done by Rao Bahadur Y. Ramachandra Rao.

ECONOMICALLY IMPORTANT GRASSHOPPERS

I. THE RICE GRASSHOPPER *Hieroglyphus banian*

This is a sporadic pest of paddy distributed all over India, Pakistan, Sri Lanka, Vietnam, Thailand and South China. The nymphs and grasshoppers generally feed on grasses over the bunds of rice fields, before attacking the crop. The leaves are completely eaten, leaving the midrib and stalk. In the earhead stage of the plants, the adult pests attack the ears or nibble at the tender florets or gnaw into the base of the stalks, leading to the formation of 'white ears.'

The adults are green, with three transverse, dark lines on the prothorax; the females measure 35 to 54 mm long including elytra and the males 28 to 40 mm long. There is only one brood per year. The grasshoppers' adults lay their eggs in soil at a depth of about 5 cm during October-November and the eggs are covered by a gelatinous substance. Each female may lay 100 to 150 eggs and the nymphal period lasts 2½ to 3 months.

Host plant Besides paddy, it feeds on sugarcane, *Sorghum, Pennisetum typhoideum* and other millets.

Control Some of the control measures are as follows:

- Trimming sides of bunds and exposing egg masses by summer ploughings for birds to peck at them.
- Dusting quinalphos 1.5% dust early in the morning or spraying 0.05% fenitrothion or endosulfan.
- Natural enemies include a fungus *Empusa grylli*, two nematodes *Gordius* sp. and *Mermis nigrescens*, grubs of *Mylabris pustulata*, the water snake *Natrix piscator* and insectivorous birds.

Other species of *Hieroglyphus* include *Hieroglyphus nigroleptus* found in India and Pakistan and also occurring on Sorghum, maize, *Setaria, Pennisetum*, etc. *Hieroglyphus oryzivorus* also occurs in this country along with *H. banian.*

2. THE SMALL RICE OR PADDY GRASSHOPPER *Oxya chinensis*
(Syn: Oxya sinensis and *O. velox)*

This species is more widely distributed, occurring in India, Pakistan, Sri Lanka, Myanmar, Indonesia, Philippines, Cambodia, Vietnam, Japan, Taiwan, Korea, China, New Guinea, Hawaii, Queensland and Mauritius. The main damage consists in nibbling at the tender florets or gnawing at the base of the ear stalk at the shot blade stage. It is a small, green or pale brown grasshopper, with a longitudinal brown streak on either side, running from the eye through the thorax, to the base of the wings. Females are about 30 mm long and the males 20 mm long. The eggs are laid in autumn in the soil and as many as 100 eggs are laid by a female and the nymphal period is about 100 days.

3. THE DECCAN GRASSHOPPER *Colemania sphenerioides*

This is a wingless grasshopper known to cause appreciable damage to rainfed millets in Karnataka and Maharashtra. In the early stages of the crop, the leaves are eaten. However, the crop suffers at the ear stage, the flowers and ripening ears being devoured wholly both by the nymphs and adults. Sometimes a total loss of crop has been met with.

The adults are wingless, greenish yellow with a purple band extending from behind the eye and laterally along the thorax, and possess blue black antennae. The females are 25 to 40 mm and the males 23 to 40 mm long. The eggs are laid in batches, 5.0 to 7.5 mm under the soil in a vertical burrow, the eggs being arranged somewhat irregularly. Each egg may contain 30 to 60 eggs and a female may lay about 100 eggs and it takes 1½ hours for the female to oviposit in the soil. The total development takes about 2½ to 3½ months.

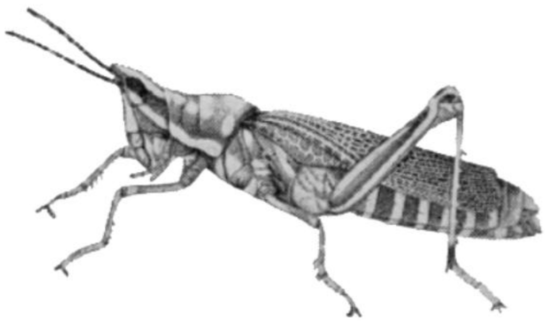
Host plants It attacks *Sorghum, Pennisetum typhoideum, Setaria italica, Eleusine coracana, Panicum miliare, Cajanus cajan. Capsicum,* cotton and rice.

Control Some of the control measures are as follows:

- Deep ploughing in previously infested fields may expose the egg masses to be destroyed. The maggots of a bombylid fly *Systaechus nivalis* feed on the eggs of the grasshopper in the soil. The grubs of *Zonabris* sp. also attack the egg masses in the soil.

4. THE AK GRASSHOPPER OR THE PAINTED GRASSHOPPER *Poekilocerus pictus*

It is distributed in India, Pakistan, Baluchistan and Africa and in India is fairly widespread throughout the plains. This is primarily a defoliator of *Calotropis gigantea*, the leaves of which are used for green manuring of fields. Hence as a pest of green leaf manure it is considered to be of importance.



▲ **Fig. 47.6** *Poekilocerus pictus—Adult (Fletcher, 1914)*

The adult is blue-black or greenish with yellow marking and red wings. The antennae are blue-black, ringed with yellow beyond the basal third of their length. The abdomen is yellow, with transverse blue-black bands. The mating takes place for five to seven hours and after a pre-oviposition period of about 25 to 30 days the female penetrates its abdomen deep into the soil and lays eggs at a depth of 18 to 20 cm. About 145 to 170 orange coloured, elongate eggs are laid in a spiral manner to form a compact mass which is covered with a frothy secretion. During autumn the nymphs hatch out from the eggs in a month and become adults in about 55 to 60 days. The eggs laid in summer overwinter for nearly four months and become adults after nymphal period of 73 to 77 days.

Host plants It has also been reported to feed on fig, citrus, papaya, lady's finger, canna, castor, cowpea, brinjal and cotton.

5. THE COLOCASIA GRASSHOPPER *Gesonula punctifrons*

This species is common in Karnataka, Orissa, Andhra Pradesh, Tamil Nadu, Kerala and Assam. It is usually found on *Colocasia* and the aquatic weed *Eichhornia crassipes* or water hyacinth.

As a leaf feeder on *Colocasia* it is a harmful insect. However, as the adults and nymphs feed in large numbers on the leaves and superficial tissues of water hyacinth, it is considered to be a beneficial insect, bringing about appreciable reduction of the plant population. The life history of this species on water hyacinth shows that oviposition takes place on the surface of the petiole in holes that are oval or circular in outline. The number of eggs in individual tunnels varies from three to eleven but most of the tunnels have only six to eight eggs. The length of the egg tunnel extends from 20 to 40 mm and found about 10 to 30 cm above water level on the petioles. The eggs are placed compactly in a group, glued together and embedded in a frothy substance. The incubation period varies from three weeks to a month. The nymphs moult five times with the total nymphal period being 28 to 38 days.

6. THE TREE LOCUST, *Anacridium rubrispinum* Bei-Bienko
(Cyrtacanthacridinae: Acrididae):

This species is prevalent in the desert area of Rajasthan, Haryana and Gujarat. Two generations; first in spring and second in summer/autumn are noticed. The egg pod containing 53–182 eggs is laid in soil at a depth of about 75 cm. Incubation period is 19–22 days. There are six to seven instars and colour polymorphism is noticed in both sexes. In nature six, seven and eight eye-striped individuals are noticed. Egg laying occurs in February and July only and the preoviposition period is 87-89 days. Life span is 53–128 days. They are active at night and attracted to light. It has no tendency to gregarise or concentrate unlike other allied species. Copulation is observed in December/January and egg laying in early February. The grasshoppers which hatch in late February/early March fledge within 8–11 weeks. These fledglings mature and lay eggs by July. Adults are usually encountered singly and prefer darkness and are active at night. They are found in crevices or hiding in bushes of castor, *Zizyphus, Calotropis,* etc.

Other Grasshopper Pests

Several surface grasshoppers cause damage to paddy in South India in the nursery stage just before transplantation. These include *Aeolopus tamulus, Acrotylus humbertiana, Pyrgomorpha conica* and *Locusta danica.* The wingless grasshopper *Orthacris simulans* occurs on *Pennisetum typhoideum.* The surface grasshoppers of cotton include the larger form *Cyrtacanthacris ranacea* and the smaller species *Catantops annexus.* Coffee plantations suffer occasionally from the attack of *Aularches miliaris* which has also been known to feed on coconut leaves in India, Myanmar, Sri Lanka, Pakistan and Thailand.

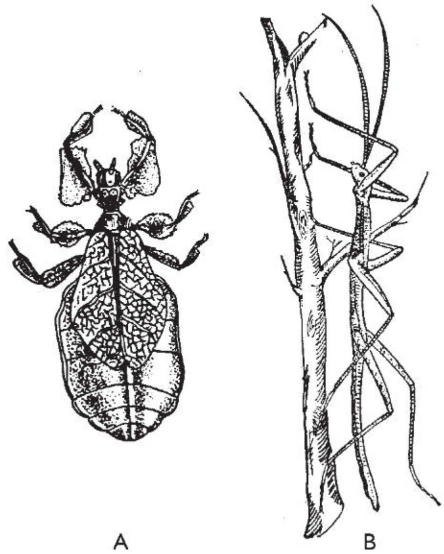
◆ Chapter 48

Order Phasmida

LEAF AND STICK INSECTS

The Phasmids are large insects with well-sclerotised bodies and they are predominantly tropical. They are particularly striking as they resemble twigs and leaves on which they live and feed.

In Phasmida two main types viz. stick or walking insects (Bacillidae) and leaf insects (Phasmidae), are recognised based on their body structure (Fig. 48.1). The stick insects possess elongate and cylindrical body and are often apterous. They resemble the twigs in colour and appearance. The leaf insects are flattened and leaf-like, winged and with lamellate expansions of the legs.



▲ **Fig. 48.1** *Leaf insect (A) and stick insect (B)*

The head is prognathous with compound eyes and in winged forms with two or three ocelli. The antennae may be filiform or moniliform with segments ranging from eight to over one hundred. The mouthparts are of ectognathous biting type. There are a pair of mandibles, a pair of maxillae each having a five-segmented palp, a two segmented galea and a lacinia, and the labium comprising of prementum, mentum, submentum, three-segmented labial palpi, glossae and paraglossae.

The prothorax is short while the meso- and metathorax are longer. Often they are wingless but in winged species the forewings are reduced and strongly sclerotised. The hindwings are membranous. In leaf insects the forewing is modified in such a manner as to simulate the veins of a leaf. The wings at rest are folded flat over the body. The legs are alike and have small coxae which are widely set apart. In leaf insects the femur and tibiae are provided with lamellate expansions. The tarsal segments are almost always five in number but rarely three. They end in post-tarsal claws and a terminal pad. A foul-smelling or unpleasant fluid is emitted from glands in the thorax in stick insects and this serves as a means of defence. No auditory and stridulatory organs are present.

Abdomen is composed of eleven segments and the eleventh segment is represented by a small epiproct, a pair of paraprocts and the cerci. Three pairs of valves constitute the ovipositor, the first pair being derived from the eighth abdominal segment and the remaining two posterior pairs from the ninth segment. The ovipositor is small and mostly concealed by the enlarged eighth abdominal sternum. In the male the genitalia are variable, asymmetrical and concealed by the ninth abdominal sternum. The cerci are short and unsegmented.

While mating the male mounts on the back of the female, curves its abdomen down behind that of the female. Copulation lasts for several hours. The eggs are laid singly over the ground and they resemble seeds very closely. The eggs may hatch within a season to several years. The young ones resemble the adults but the time taken for development may vary with different species. Males develop quickly and undergo one or two fewer moults than that of the female. The adult males are also short-lived. The wing-pads do not undergo reversal during development. Parthenogenesis is not uncommon and in certain species males are unknown. Another interesting feature is, unlike other insects, the nymphs of phasmids have abscission suture between femur and trochanter, and if injured, regeneration takes place resulting in four-segmented tarsus. Many stick insects, especially those which are brown, have the ability to change colour from dark to pale or from brown to green in response to light intensity and this is attributed to integumental chromatophores. Here colour change is more rapid and is found to be mediated by neurosecretory discharges. It has also been claimed that two principles (probably hormones) are involved.

About 2500 species are known so far, the majority being from the Oriental tropics. The giant Australian stick insect is the longest in the world measuring about 33 cm excluding the antennae. *Carausius* is a well known genus of stick insect and *Phyllium* of a leaf insect. The following two families are recognised.

Family Phylliidae

Thick-set insects, occasionally flattened and leaf-like; a triangular apical area on tibiae present; e.g. *Phyllium, Clonopsis, Timema.*

Family Phasmatidae

Elongate and not thick-set; never leaf-like; a triangular apical area on tibiae wanting; e.g. *Carausius, Lonchodes, Megacrania, Clitumnus.*

◆ Chapter 49

Order Dermaptera

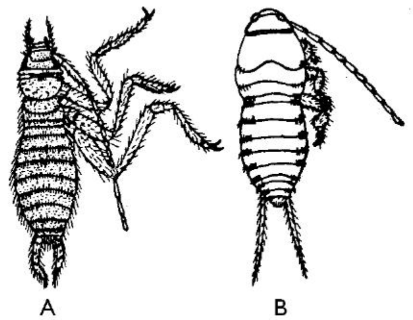
EARWIGS

The Dermaptera include insects popularly called the earwigs, mostly living concealed in the soil, under stones and bark, and abundant in the tropics, the new and the old world. They are usually associated with Orthoptera and Phasmida though they have characters in common with blattids.

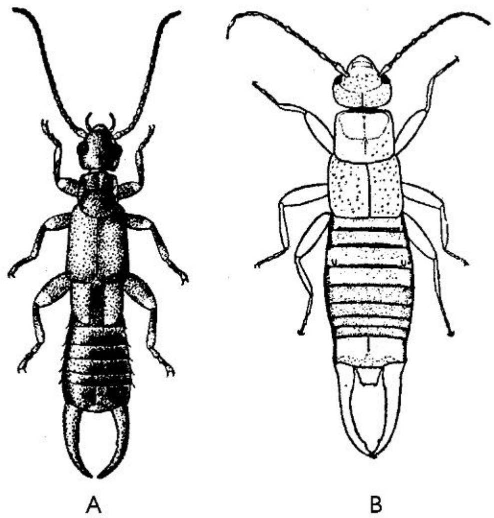
The integument is well sclerotised and sutures on the small, rounded to broadened, prognathous head are distinct, in particular, the 'Y' shaped epicranial suture. The head is more flattened, with a broad facial aspect and the prognathous condition is the result of the lengthening of the ventral margin of the cranium (the hypostoma) and hence called the hypostomal elongation. In general the chief features of the head-form are due to genal expansion, hypostomal elongation, the forward position of the eyes, antennae and mandibles (Henson, 1950).* The number of antennal segments is variable, between ten and fifty. The compound eyes are normally well developed, but in the ectoparasitic Arixenidae, they are vestigial and absent in *Hemimerus* (Fig. 49.1.) The mouthparts are typically mandibulate, the mandibles strong, chitinised, bearing two apical teeth. The clypeus and labrum are large, separated by a well defined clypeolabral suture. The clypeus is bound by the strong epistomal suture and is divided into the ante and postclypeus. The maxilla and labium are as in orthopteroid insects, except that the labium bears a single pair of lobes, the ligula. The hypopharynx is well developed, as also the large superlinguae.

* Henson, H.E. 1950. *Proc. R. ent. Soc. London., (A),* **21**: 10–18.

The neck or cervix is distinct, leading into a more or less quadrangular pronotum. The metanotum is fused with the first abdominal tergum. The legs are almost similar, five-segmented and with three-segmented tarsi. The wings are very characteristic of the order, the forewings being modified into very short, leathery tegmina devoid of all veins. The hindwings are membranous, semi-circular and concealed under the tegmina, being folded longitudinally fanwise, along with two transverse folds (Fig. 49.2). The anal area of the semicircular wing is greatly expanded and the veins of the wing are highly modified and disposed of in a radial fashion. Some species of *Anisolabis*, *Arixenia*, etc. lack wings.



▲ **Fig. 49.1** *A. Arixenia esau, B. Hemimerus talpoides (R. Jeannel, 1960)*



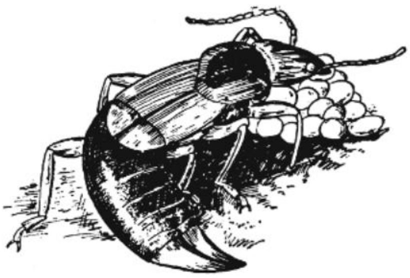
▲ **Fig. 49.2** *A. Nala lividipes (T.B. Fletcher, 1914), B. Marava arachidis (after Hincks)*

The abdomen is made up of 11 segments, the eleventh being represented by a small pygidium. In the females, the eighth and ninth segments are telescoped under the seventh, while in the males they are distinct, the tenth segment is being represented by a pair of plates, at the base of the cerci. These are unjointed and modified into a well sclerotised, strong forceps, showing sexual dimorphism and varying in size and shape in the various species.

The ovipositor is mostly lacking in the females, but some Pygidicranids possess a primitive ovipositor. However, the male genitalia show great complexity, consisting of a pair of penes with individual ducts or a single penis with both ducts or only one duct. The origin of the penes is double, its rudiments comparable to those of Ephemeroptera. The paired penes, a primitive feature, is characteristic of the labidurids. There is a long basal stalk with two apical lobes and both the mesomeres and parameres are distinct lobes. In *Hemimerus* there is a single penis with two parameres but the mesomeres unite to form a median lobe, giving exit to two primary ducts. In the forficulids also, there is a single median lobe, but one duct is abortive, the other functional and the median lobe unlike as in *Hemimerus* appears to be derived from the right mesomere of the nymph, the left one being reduced or obliterated.

In the alimentary canal, the oesophagus leads into the crop followed by a globular proventriculus or gizzard. The proventriculus has six longitudinal folds bearing small scale-like projections with a cushion of bristles at the anterior end of each fold. Gastric caeca are absent and the malpighian tubules 8 to 20 in number are arranged in bundles. Six rectal papillae are present in the rectum. The respiratory, circulatory and nervous systems are typically as in the Orthoptera. In the female reproductive system, there are five elongate panoistic ovarioles as in labidurids. The number of ovarioles appear to vary in different genera. In *Hemimerus* there are eight or ten to twelve, or much fewer in *Arixenia*; but in *Forficula*, the numerous ovarioles are very short, polytrophic, disposed of in three rows, being arranged at regular intervals along the oviduct. In *Marava arachidis* the ovaries are paired, but unique in consisting only of a single ovariole, with eight to twelve oocytes. In *Arixenia* and *Hemimerus* on the other hand each ovariole has only a single egg and reproduction is viviparous. In *Hemimerus* as earlier mentioned, the embryo is fed through pleura-like structures, developed from the maternal tissues which lie in contact (or fused) with processes from the body of the embryo to help in the transfer of nutrients. In *Marava* a simple viviparity occurs without organs for transfer of nourishment. Both the eggs contain sufficient yolk to nourish the young until hatching.

The male reproductive system also exhibits profound variations in structure, from paired, closely apposed, elongated bodies on each side as in *Anisolabis*, *Forficula* or more filiform in *Arixenia* or compact, globular and composed of 16 follicles as in *Hemimerus*. The slender vasa deferentia dilate into seminal vesicles posteriorly. The parental care of eggs and young is very characteristic of female earwigs. The eggs are laid in clusters in the soil in a group and the female guards them (Fig. 49.3). The nymphs are like the adults, except that the antennal segments are fewer. In Diplatyinae and Karschiellinae, the forceps of the nymphs are unlike as in the adult, being thin and 14- to 45-segmented, cerciform or styliform. In all other earwigs the forceps occur also in the nymphs and segmented cerci are absent.



▲ **Fig. 49.3** *Parental care in an earwig*

The affinities of Dermaptera have been discussed by several workers; Walker (1919) with Embioptera and Plecoptera; Handlirsch (1908, 1925) to Grylloids; Chopard (1949) to Coleoptera; Snodgrass (1939) as distinct from Orthoptera and Quadri (1940)[1] to Ephemeroptera. The work of Giles (1963)[2] presents a new approach to the study of affinities, based on 283 characteristics. He concludes that Forficulina, Hemimerina and Arixenina should remain as three suborders of Dermaptera, and that they show the greatest affinity with the Grylloblattodea, which has been confirmed by the evaluation of the incidence of the dermapteran characters of the Grylloblattodea.

Suborder FORFICULINA

Mandibles dentate at apex and base. Forceps well sclerotised; wings well developed; free living forms with well developed eyes.

SUPERFAMILY PYGIDICRANOIDEA

Family Pygidicranidae

Paired aedeagus distinct; Telson and tergum of eleventh segment also distinct; forefemora compressed and keeled. Telson as large as pygidium.

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1. Quadri, M.A.H. 1940, *Trans. R. ent. Soc. London,* **90**: 121–175.

2. Giles, E.T. 1963. *Trans. R. ent. Soc. London,* **115**: 95–164.

Family Diplatyidae

Paired aedeagus with four gonopores; e.g. *Diplatys*.

SUPERFAMILY FORFICULOIDEA

Family Forficulidae

Aedeagus unpaired; tergum of tenth segment well developed; eleventh tergum and telson reduced or absent; second tarsal segment bilobed and dilated; e.g. *Forficula auricularia, Allodahlia*.

Family Labiduridae

Paired aedeagus. Telson smaller than pygidium; forefemora not compressed and keeled; e.g. *Labidura riparia, Forcipula quadrispinosa, Nala lividipes, Anisolabis maritima*.

1.* THE GROUNDNUT EARWIG *Anisolabis annulipes It is the common groundnut earwig in India. Both nymphs and adults bore into tender pods and feed on the kernels. Damage of 20 to 65 per cent has been reported. Pod damage is high in summer groundnut. It also feeds on vegetable material, onion bulbs, cotton bolls and sorghum stem. This species is distributed in Israel, Europe, America, Asia and Hawaii. The adult is elongated, wingless, brownish and measures 30–35 mm long. Mating takes place 7–10 days after emergence and commences egg laying 10–23 days after mating. The eggs are laid in clusters on pods or in soil. Fecundity is 21–108 eggs. Incubation period is 3–11 days. There are four or five nymphal instars and the nymphal period being 34–60 days. Adult longevity is 106–252 days. Life-cycle is completed in 56–101 days. Soil drenching at 40 DAS with endosulfan 35 EC at 2.25 l/ha or carbaryl 50 WP at 3 kg/ha or incorporation into soil at sowing of methyl parathion 2 dust at 40 kg/ha have been reported to be useful in minimising damage by earwigs.

Family Chelisochidae

Aedeagus unpaired and tergites of tenth and eleventh segments as in other forficulids. Second tarsal segment with a narrow lobe extending beneath the third segment; *e.g. Chelisoches morio*.

SUPERFAMILY LABIOIDEA

Family Labiidae

Second tarsal segment unlobed and dilated. Otherwise as in Forficulidae and Chelisochidae with unpaired aedeagus; *e.g*: *Labia, Prolabia, Marava arachidis, Spongivora.*

Family Carcinophoridae – *e.g: Parisolabis, Epilandex undulata.*

Suborder ARIXENINA

Family Arixenidae

Apterous, eyes vestigial, ectoparasitic mostly on bats, cerci or forceps very weak and setose, mostly arched. Mandibles strongly flattened with dense hairs on inner margin and toothed only at apex. Antennae long, 13 segmented; legs comparatively short. Represented only by a single genus *Arixenia*, with two species, *A. esau* parasitic in the gular pouches of the bat in Malaya and *A. jacobsoni* from Java. Both are viviparous.

Suborder HEMIMERINA

Family Hemimeridae

As in Arixenina, this suborder is also represented by a single genus *Hemimerus* ectoparasitic on rats, and are apterous, flattened, without eyes having unjointed, feebly sclerotised cerci or forceps. The thoracic segments are laterally expanded broader than abdomen, the prothorax being very broad. Legs short and tarsi triarticulate. Viviparous, developing a placenta. Food consists of epidermal products of the host like hairs, scales, etc. Several species of *Hemimerus* are known, *H. talpoides* is the commonest species.

◆ Chapter 50

Order Embioptera

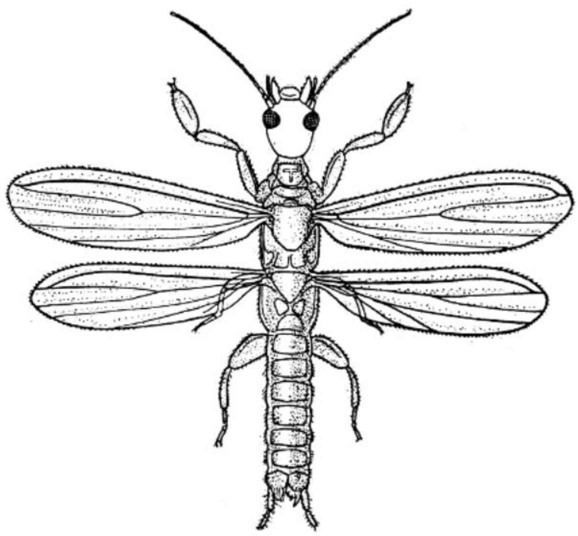
WEBSPINNERS

The embiids or webspinners as the Embioptera are popularly referred to, comprise a comparatively small order of elongate insects with a soft integument and occurring usually beneath stones, in crevices of bark, under bark flakes or lichens. They live in silken tunnels, some species producing a conspicuous mat of such-tunnels occupied by a large number of individuals, while others form only individual colonies. By distribution they are found in all the zoogeographic regions and are especially abundant in the tropics.

The head is prognathous with typically mandibulate mouthparts, without an epicranial suture, without ocelli, with small compound eyes and a filiform antenna made up of 15 to 30 segments. The prothorax is narrower than the head, while the pterothorax comprised of subequal meso- and metanota, shows clear dimorphism, being narrow and elongate in the female and short and broad in males. The middle pair of legs are reduced, while the hindlegs have swollen femora. The forelegs are well developed and the first foretarsal segment is inflated to accommodate numerous glands which produce silk for the construction of tunnels. Each glandular chamber is surrounded by a layer of epithelial cells with a central area filled with the secretion. There are 70 or 80 glandular chambers and these are in communication through fine ducts with several hollow bristles, so that each gland discharges its secretion ventrally at the apex of its related bristle. Only the males are winged, they being subequal in size and shape, with numerous microtrichia. The venation is generally reduced, but the radial vein is greatly thickened and in the oligotomids the venation is very much reduced (Fig. 50.1). The Embiidae show a more complex venation with R_{4-5}

forked and M and Cu distinct and branched, while in Oligotomidae R_{4-5} is unforked and M is almost vestigial and Cu is unbranched.

The abdomen is made up of ten segments, the tenth tergum in the male being comprised of a pair of asymmetrical plates called the hemitergites and entire in the females. In only one primitive genus *Clothoda* the tenth tergum is unchanged in the males, while in all others the tenth segment and the cerci they bear, are asymmetrical, and are modified for copulation. The cerci are two-segmented, carried on the tenth segment, symmetrical in the females, the left one in the males being modified. The sternum of the ninth segment is asymmetrical in males and is the subgenital plate and the phallus or aedeagus is vestigial or absent. The left and right hemitergite bear processes or paraprocts which are of various shapes and differently sclerotised in the various genera.



▲ **Fig. 50.1** *An oligotomid*

The alimentary canal is a straight tube, with a pair of long salivary glands and with 20 to 30 malpighian tubules. There are ten pairs of spiracles and the nervous system has the brain, suboesophageal ganglion, three thoracic and seven abdominal ganglia. The reproductive system is primitive. The females have five panoistic ovarioles which are segmentally arranged and opening at intervals along the oviduct. The testes in the males have also five lobes. Eggs are laid in silken tunnels, the developing nymphs also having the capacity to form tunnels. Under natural conditions the number of eggs laid by *Oligotoma humbertiana* is 60 and varies from 15 to 24 under captivity.

Maternal care is exhibited by the females. When a female with eggs and young ones, is disturbed by peeling off the bark under which the tunnel is, she darts backwards with alacrity and also tries to repair the damaged part of the tunnels by spinning very busily. After copulation the female is left alone in the tunnel. The young ones of a brood live gregariously in the tunnel built by the mother, up to the nymphal stage and the nymphs on the eve of their becoming adults move apart and spin tunnels themselves. On starvation, both sexes assume cannibalistic trends. In general, the females live for a longer time and as seen under laboratory conditions the females live for nine months and males five months.

Family Oligotomidae (oligotomids)

Tenth tergite in males asymmetrical; usually with R_{4-5} forked; without echinulations on inner surface of basal segment of left cercus. Instars of both sexes lacking median or second tarsal bladder on the plantar surface of the hind basitarsus; e.g. *Oligotoma humbertiana, O. minuscula*, *O. falcis*, *O. saundersii*, and *O. greeniana* are Indian species. *O. greeniana* adults live in spider nests.

Family Embiidae (embiids)

Tenth tergite in males asymmetrical; wings with a more complete venation, with R_{4-5} forked; echinulations are distinct on inner surface of basal segment of left cercus; two second tarsal bladders in all instars; *Embia* (*Parembia*) *valida*, *Embia* (*Parembia*) *minor*, *Metembia ferox*, *Pseudembia paradoxa*, *Pseudembia flava*, *Pseudembia immsi*; *Embia termitophila* occurs in nests of termites. The other families of Embioptera recognised are: Clothodidae, Notoligotomidae, Embonychidae, Anisembiidae, Australembiidae and Teratembiidae.

◆ Chapter 51

Order Dictyoptera

COCKROACHES AND MANTIDS

This order includes the terrestrial blattids or cockroaches and the mantids, which are tropical and subtropical in distribution. The cockroaches have dorsoventrally flattened bodies, a large shield like pronotum and well developed legs for running, while the mantids are predaceous with raptorial forelegs, a long and slender prothorax and mid- and hindlegs.

The blattids are the oldest living insects closely related to the Palaeodictyoptera, with a hypognathous head bearing all the typical sutures and sclerites. The mandibulate mouthparts comprise the strongly chitinised, toothed mandibles, maxillae with toothed, setose lacinia, a simple galea and five-segmented palps; the labium bears a large submentum, a small mentum and a prementum with well developed glossae and paraglossae and three-segmented labial palps. The well developed hypopharynx has a median depression at base, the sitophore and lateral sclerites. The eyes and ocelli are large particularly in the mantids, where there are three ocelli. They are degenerate in blattids and are represented by the fenestrae.

The cervical sclerites are well developed in the neck region. In the thorax the large shield like pronotum of blattids and the elongate prothorax in mantids, are freely movable. The meso- and metathorax are subequal. The legs are five-segmented and coxae of the legs in the blattids are large and closely approximate and adapted for running. In the mantids the forelimbs are modified into raptorial legs, the coax long and movable, the forefemora bearing a ventral longitudinal groove with strong spines at its edges. The spinose blade-like tibia fits into this groove, and its apex is produced into a hook. Its sharp-toothed edge impales the prey against the femur. The forewings in blattids have a leathery consistency, sometimes more chitinised and are called the tegmina, serving to protect the membranous hindwings which have a large anal lobe.

There are ten distinct segments in the abdomen, a reduced eleventh and in the females the seventh sternum and in the males the ninth sternum is enlarged and modified to form the subgenital plate. The sternum of the eleventh segment is divided to form the paraprocts carrying the segmented cerci. The ovipositor is composed of three pairs of valves, the first and second subequal and is contained in a cavity or vestibulum formed by the enlarged seventh sternum. In the male genitalia the two primary phallic lobes become split horizontally to form four lobes, two dorsal and two ventral and these remain as such to surround the gonopore or become variously combined to form complex genital structures. In *Periplaneta* the two lobes on the left side unite and form a complex left phallomere. The right dorsal phallomere bears hooks and spines and overlaps the left. The right vestigial phallomere remains as a simple lobe. Modifications of various types occur in the different species.

The alimentary canal is simple, straight or coiled. The crop is well developed, but the gizzard may be absent or poorly developed as in mantids and well developed as in cockroaches. The gizzard is conical and joins the crop at its broad base. Eight tubular gastric caeca of the midgut arise at the proximal end of the midgut immediately posterior to the proventriculus. The gizzard bears six sclerotised teeth, alternating with a varying number of folds or spine bearing patches. In the mantids also the proventriculus is similar, but anastomosing ridges are present, alternately with the teeth. The malpighian tubules are numerous, 80 to 100 in number. Well developed salivary glands and salivary reservoirs are present. The tracheal and nervous systems are of the generalised type, with ten pairs of spiracles and some of the abdominal ganglia fused to result in 4 to 7 separate ganglia. The heart consists of 12 to 13 chambers extending through the thorax and abdomen, with 12 pairs of lateral alary muscles and 12 pairs of ostia in the cockroaches, but in mantids the number of ostia is reduced. In the male reproductive system the testes are composed of four or more follicles enclosed in a sheath; the vasa deferentia are simple tubes and arising anteriorly from them are a number of tubular seminal vesicles, presenting frequently a mushroom-like appearance. A club-like unpaired conglobate gland also opens into the genital pouch. The ovaries in the female consist of a variable number of panoistic ovarioles (6 to 20 in various genera) and lead by short ducts into the oviduct, opening in turn into the genital chamber. The spermathecal duct opens dorsally into the genital chamber. The duct of the colleterial glands also open into the genital chamber. In the blaberids, where there is viviparity, there appears to be a distinct evolutionary trend towards a decrease in the total number of ovarioles per ovary. In ovo-viviparous and viviparous blaberids there is also a marked reduction in the number of oocytes. In the blattids the maximum number of oocytes containing yolk per ovariole is two or three, while in blaberids it is only one.

The eggs of cockroaches are usually arranged in a double row and enclosed in a membranous sac or in an ootheca formed by the secretions of the colleterial glands. The left glands secrete a protein, phenoloxidase and calcium oxalate, while the right gland secretes protocatechuic acid. Simultaneous action of both glands results in enzymatic conversion of protocatechuic acid into a quinone so that the ootheca becomes hard and dark. The protein secretion is under the control of the juvenile hormone. In all cockroaches the newly formed ootheca projects from the abdomen of the female vertically. All the blattids and some blaberids carry the egg case without changing their position, while in others the female rotates the ootheca through 90° so that the keel faces laterally when it is deposited. An advantage in rotation appears to be that it would permit the uterus to increase in size as the embryos develop. If no rotation takes place, the long axis of the eggs would lie vertically and during gestation the uterus would have to stretch dorso-ventrally. The oothecae of the cockroaches vary in size, sculpture and the position in which they are carried.

Habits

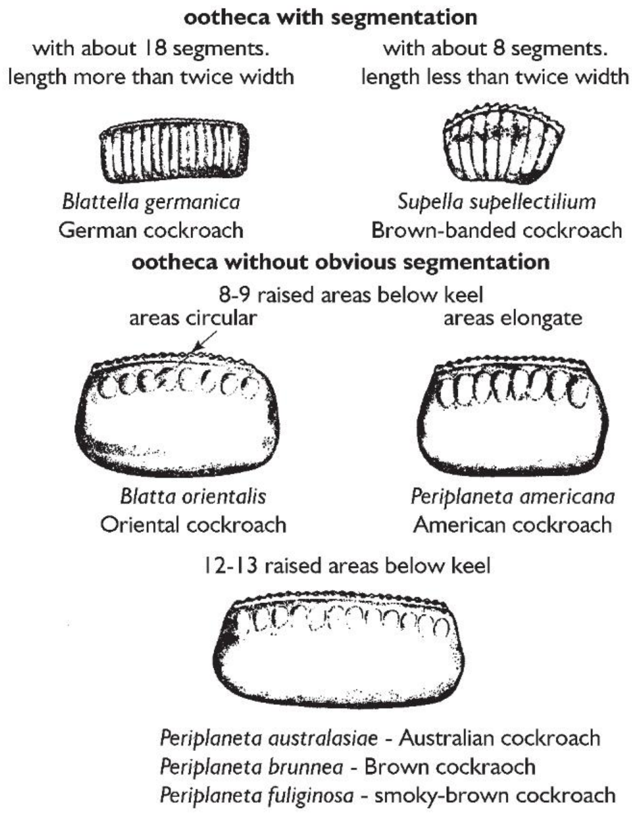
Cockroaches are mostly tropical and Indo-Malayan in distribution, though many species occur in the temperate regions. The domestic cockroaches include *Blatta orientalis, Periplaneta americana, Supella supellectilium* and *Blattella germanica*. *Attaphila* sp. is myrmecophilous, *Panesthia* and *Cryptocerus* sp. are wood feeding with symbiotic bacteria and protozoa in the gut. Some species like *Trichoblatta sericea*, *Nauphoeta* are ovo-viviparous. Others like *Leucophaea maderae* are viviparous. The seven-spotted cockroach *Theria petiveriana* (Fig. 51.1) has a very strong ootheca.

Three principal systems of classification, after Rehn (1951),[1] Princis (1960)[2] and Mckittrick (1964)[3] have been discussed by Roth (1970).[4] The classification of Mckittrick is based on the female genitalia and musculature, male genitalia, proventriculus and oviposition behaviour and is supported by the noted works of Roth on various aspects of reproduction, of Huber (1968) by numerical taxonomical studies on cockroaches, and of Leconte *et al*., (1967) on the malpighian tubules of cockroaches.

Suborder BALATTARIA

Dictyoptera with head almost covered with large pronotum, with two ocelli represented by whitish fenestrae. Forelegs not raptorial and gastric armature strong.

1. Rehn, J.W.H. 1951. *Mem. Amer. Ent. Soc.,* **14**: pp 134.
2. Princis, K. 1960. *Orthopterorum Catalogus, Partes* **3–14**, pp 1224.
3. Mickittrick, F.A. 1964. *Mem. Cornell. Univ. agric. Exp. Sta.,* **389**:pp 197.
4. Roth, L.M. 1970. *Ann. Rev. Ent.*, **15**: 75–96.



▲ **Fig. 51.1** *Oothecae of cockroaches (Courtesy: Rentokil Labs. Ltd., East Grinstead)*

SUPERFAMILY BLATTOIDEA (OVIPAROUS)

Family Blattidae

Heavily pigmented species; pronotum concealing head; tenth tergite of male more or less quadrate; cerci well developed and styles very distinct; seventh sternite of female forming a pair of valves. Femora armed with strong spines. E.g. *Blatta orientalis, Periplaneta americana, Neostylopyga rhombifolia.*

Family Cryptoceridae

Pronotum not completely concealing head. Tegmina strongly sclerotised. Subgenital plate of male with style and cerci reduced in both sexes. E.g. *Cryptocerus punctatus.*

SUPERFAMILY BLABEROIDEA (VIVIPAROUS)

Family Polyphagidae

Large, broadly convex species; anal field of hindwings small. e.g. *Polyphaga indica.*

Family Blatellidae

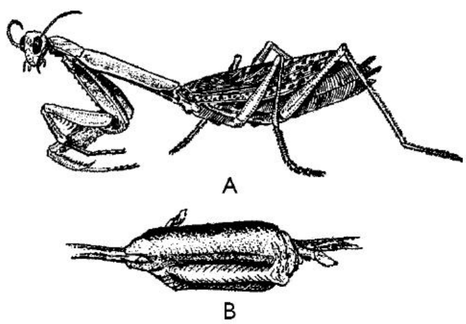
Ovo-viviparous species. Eggs carried by the female for most of the incubation period in a sclerotised or membranous ootheca. E.g. *Blattella germanica, Supella supellectilium.*

Family Blaberidae

Viviparous species with eggs retained until hatching in the enlarged genital chamber or brood sac of female. Femora unarmed; subgenital plate asymmetrical in male; and field of hindwings large and folded; seventh sternite of females not forming a pair of valves. E.g. *Nauphoeta cinerea, Pycnoscoelus indicus.*

Suborder MANTODEA

Dictyoptera including the mantids (Fig. 51.2) with head not covered by pronotum, with three dilate ocelli, raptorial forelegs, gizzard not powerfully armed, carnivorous, feeding voraciously on flies, caterpillars, grasshoppers. *Mantis religiosa* is the common species, with a typical greenish hue, but several other species exist differing in size, colouration and habits. *Gongylus gongyloides* is another common Indian species. The female lays eggs in ootheca, attached to twigs or other objects, each female producing sometimes as many as over 20 egg cases. In *Gongylus* it is made up of a frothy secretion, hardening into a firm, spongy structure and within it are about 40 egg chambers. The number of instars in mantids do not appear to be constant and varies between 3 to 12 and the life-cycle takes about a year to be completed.



▲ **Fig. 51.2** *A – Preying mantis adult, B – egg case*

◆ Chapter 52

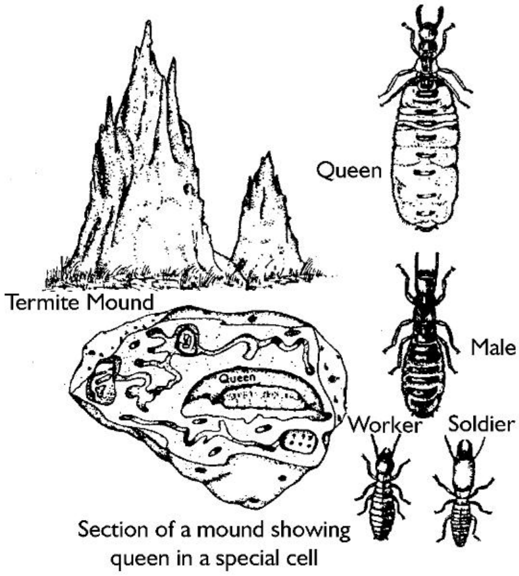
Order Isoptera

TERMITES OR WHITE ANTS

The members of this order include the termites or white ants which are social insects, living together in organised communities composed of mature males and females and sterile workers and soldiers (Fig. 52.1). They abound in the tropics and warm temperate regions. The name Isoptera refers to the two pairs of similar wings which are readily cast off along a line of fracture at their bases. In view of the fact that many termites feed on the cellulose of wood and cause serious damage, awareness of their behaviour patterns has economic consequences.

The head is prognathous, oval to rounded, sometimes enlarged as in the soldiers, with moderately well developed sutures and bearing a pair of moniliform antennae made up of 9 to 30 segments and varying with species and individual castes. Compound eyes are well developed in winged forms and reduced or absent in the others. The mandibulate mouthparts are typically orthopteroid in make up, the mandibles acquiring a variety of size and shape in the soldiers of different species. In the maxilla, the lacinia is toothed apically, galea hood-like and the palps are five-segmented. The labium has a large basal plate or postmentum bearing anteriorly the prementum carrying the glossae and paraglossae and a three-segmented labial palp. The hypopharynx is distinct and lacks the superlinguae.

Neck is characterised by presence of the cervical sclerites. The prothorax is freely movable as in Orthoptera and the shape of the pronotum highly variable, while the meso- and metanota are subequal. The legs are similar, short and stout, with enlarged coxae and the tarsi are generally four, rarely five-segmented. Between the claws is an empodium. The wings which are alike, long and membranous are characteristic of sexually mature males and females. The veins of the basal part are more sclerotised and cross veins are absent. In the primitive Isoptera, the costa is absent, while in the highly evolved species, it is greatly thickened. The Sc may be two-branched, R-R_5 recognised as separate branches or R may be represented by a single vein. Both M and Cu are well developed. The wings have a basal line of weakness, often termed the humeral suture, where the wings break off and are shed. Only in the primitive *Mastotermes* this suture is absent and the wings become irregularly torn off.



▲ **Fig. 52.1** *Termite mound, entire section of a mound showing queen in a special cell, and reproductive castes (after Imms, Textbook of Entomology)*

There are ten segments in the abdomen, the tergites 10 and 11 being often fused, while the sternum of the eleventh segment is represented by a pair of paraprocts bearing the cerci as in the blattids. The sternum of the first segment is reduced. In the males all the sterna are entire except the ninth, while in the females, the seventh sternum forms the subgenital plate. The cerci have a variable number of segments, one or two, three to six, or six to eight and small styli may also be present on the ninth sternum. The ovipositor is reduced in the female and the phallic organs of the male are also greatly reduced or suppressed and in a few species there is a small penis, but parameres are always absent.

The alimentary canal has the oesophagus leading into a crop variable in size and with a ring-like or more pronounced gizzard, bearing an armature of cuticular denticles. At the anterior end of the midgut are four or five gastric caeca. The malpighian tubules may be eight in *Kalotermes* or two to four in others, particularly in Termitidae. The salivary glands are well developed and with large reservoirs. The circulatory, respiratory and nervous systems present no striking features, the circulatory system with 8 to 10 chambered heart, the respiratory system with two thoracic and eight abdominal spiracles and nervous system with three thoracic and six abdominal ganglia. The "frontal gland" is a structure peculiar to the soldiers, situated on the frons and communicating with the exterior by a pore and discharging a secretion, which appears to possess a defensive function. The organs of reproduction are aborted or reduced in workers and soldiers and well developed in the reproductives. Rarely, as in the soldiers of *Archetermopsis*, sexual organs are well developed. The testes comprise 8 to 10 short lobes with the short vasa deferentia uniting to form a muscular ejaculatory duct. In the ovary, the panoistic ovarioles are variable in number, 30 to 45 in the queen. These open separately into paired oviducts which in turn open into the subgenital pouch. The colleterial glands and spermatheca also open into the subgenital pouch

Termite Castes

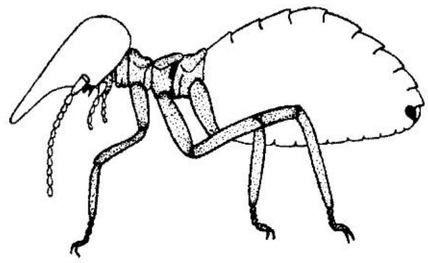
Two main categories, the reproductive castes and sterile castes are recognised. The reproductives comprise the primary reproductives including the winged adults having two pairs of large membranous wings, with sclerotised dark coloured bodies and with well developed compound eyes and ocelli. They come out of their nests in large numbers and after a brief aerial existence, shed their wings. After fertilisation, the females in primitive genera do not undergo any perceptible change of form, but in Termitidae the queen attains enormous proportions. This obesity is known as physogastry, the increase affecting only the abdomen and not the head or thorax. The ovaries and fat bodies greatly increase in size. The original tergal and sternal plates become widely separated owing to the growth of the intersegmental membrane. The kings are males which undergo little morphological change, but become more flattened and both sexes receive a prepared diet from the workers. The queens produce at least a million egg per year and live for many years.

Supplementary reproductives are apterous or brachypterous with little sclerotisation, poorly developed or reduced eyes and ocelli. They may be present among the offspring of the primary reproductives and not normally found in colonies and appear to replace the primary reproductives when the latter die.

The workers and soldiers form the sterile castes which are apterous and with non-functional reproductive organs arrested or atrophied (Fig. 52.2). The workers which are more numerous have poorly sclerotised, non-pigmented bodies with a small brain and reduced eyes. The head is wider than in reproductives and is directed downwards and the mandibles stronger and used for gnawing wood. The workers also tend the eggs and the young ones, forage for food and construct nests or termitaria. In the lignicolous species the workers excavate galleries and tunnels which form their nests and it is their efficiency at gnawing wood that has brought notoriety to the termites as destroyers of wood. Sometimes the workers may be dimorphic with major and minor forms, the head and mandibles being larger in the major forms.

The soldiers have large, highly sclerotised heads more or less pigmented bodies with mandibles very prominent in size and shape, often assuming bizarre shapes and have fully developed frontal glands (Fig. 52.3). Eyes are vestigial. Soldiers may be trimorphic or dimorphic with large, medium sized and small individuals. In some soldiers there is a median rostrum and the mandibles are vestigial. These are called the nasutes and are mainly concerned with the defence of the colony and have well developed frontal glands producing a pungent secretion so that the mandibles are not an absolute necessity.

In addition to the main castes discussed above in some termites like *Kalotermes*, a



▲ **Fig. 52.2** *Nasute of Nasutitermes (after Kumar Krishna & Frances M. Weesner, 'Biology of Termites', Academic Press, 1969)*

▲ **Fig. 52.3** *A termitarium near Kargudi, Nilgiris (India) (Courtesy: W. Buttiker, Revue Suisse de Zoologie, 1967)* primitive one, is characterised by the presence of pseudergates. There is no fixed worker caste and the functions of the workers are performed by full grown larvae termed pseudergates. After about five to eight larval stages the full grown pseudergates have the potentiality to develop along different path ways in the adult direction or soldier or become supplementary reproductives.

Caste Differentiation

The production of supplementaries in termite colonies appears to be inhibited by the production of pheromones which circulate from individual to individual throughout the colony. The action of the pheromones is believed to be very specific and influences the endocrine system. In *Kalotermes*, it has been shown that the male pseudergates seem to inhibit the development of female supplementaries and *vice versa*. In addition, the male reproductives give off a stimulatory factor which in turn stimulates the production of male supplementaries. That the pheromones interfere with the endocrine system has equally been demonstrated by Luscher* who induced soldier development in competent pseudergates by implanting corpora allata of reproductives. However, no effect was found on the pseudergates when corpora allata of pseudergates were implanted thereby showing that the gonadotropic hormone of the corpora allata induces soldier differentiation and the juvenile hormone promotes development of supplementary reproductives. Further, the pheromones which inhibit supplementary reproductive development are also believed to have an inhibitory effect on the neurosecretory system or the prothoracic gland.

Nests of Termites

Termites occur in the soil in very large numbers, burrowing into the ground, constructing a series of complex tunnels with or without a mound. The primitive species construct no nests but feed on wood and make galleries by gnawing. The termitaria or mounds of higher termites are huge or gigantic structures attaining a height of more than 3 m with a basal diameter of 3 to 4 m. They are very strong and durable and built up of mud particles cemented together by means of their saliva and faecal cartons and upon drying assume a cement hardness. It is not ordinarily possible for animals and even man to destroy them. In the interior are a network of irregular chambers and passages and the royal cell is located in the innermost chambers. A series of nests with numerous subterranean runways and grass storage areas are found in a single colony. Interestingly enough the most primitive *Mastotermes darwiniensis*, a subterranean dwelling termite, (though basically wood feed-

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* Luscher, M. 1961. Social control of polymorphism termites. *Symp. R. ent. Soc. Lond.* **1**: 57–67.

ing) constructs passages above the ground. Most Kalotermitidae are wood dwelling, wood eating, while the Rhinotermitidae are basically subterranean, penetrating the soil, with the nests being located in buried wood and sometimes above the ground. The Termitidae are also subterranean but many build mounds or arboreal nests. The subfamily Macrotermitinae construct fungus combs as in *Odontotermes.*

As to their feeding habits, the termites indiscriminately feed on living and dead plant parts, faecal matter of other castes, exuviae and dead members of the colony and are hence omnivorous. The kings and queen and young ones are fed by the workers (*Trophallaxis*) with regurgitated food and saliva. There is a peculiar habit of licking or tending the queen by numerous workers because she produces copious secretions. Some termites grow fungus beds in special chambers in the nest and these appear to be spongy, dark reddish brown comb of vegetable matter. Fungi readily germinate on this bed and their fruiting bodies provide nutriment for the young and royal pair. The wood feeding termites are unable to utilise the ligneous matter and no enzymes are also present to make the food digestible. As an adaptation the digestive tract contains numerous trichonymphid mastigophoran Protozoa which help in cellulose digestion. Experimental killing of the gut fauna brought about the death of the termites and when reinfected many survived. The wood dwelling, wood eating habits of Kalotermitidae and Termopsinae (Hodotermitidae) represent the primitive feeding types.

Distribution

Termites are well represented in fossil records. Mastotermitidae is mesozoic and the only living representative of this family is *Mastotermes darwiniensis* in Australia. Morphologically the Hodotermitidae are also primitive and well represented in fossil records, and of the living genera, *Hodotermes* is Ethiopian, *Anacanthotermes* is Indo-Malayan and *Porotermes* is Ethiopian, Australian and Neotropical in distribution. The Kalotermitidae also include the most primitive forms and occur in the Neotropical and Palaearctic and are also recorded as fossils. Of the Rhinotermitidae, the most primitive are Indo-Malayan and the most highly evolved are neotropical in distribution. All the members of the Termitidae are typically Indo-Malayan.

Family Mastotermitidae

Primitive, well represented in fossil record, with tarsi five-segmented and hindwings with well developed anal lobes. e.g. *Mastotermes darwiniensis.*

Family Kalotermitidae

Primitive, wood-dwelling termites without workers, but with pseudergates or pseudo workers. Pronotum flat, broader than head; wings without anal lobe. e.g. *Kalotermes, Neotermes, Glyptotermes.*

Family Hodotermitidae

Wood inhabiting, with pronotum narrower than head, tarsi imperfectly five-segmented and without anal lobe on hindwings. e.g. *Hodotermopsis, Archetermopsis, Zootermopsis.*

Family Rhinotermitidae

Subterranean termites with pronotum of workers and soldiers flattened, wings often reticulate and without anal lobe on hindwings. e.g. *Rhinotermes, Reticulotermes, Coptotermes.*

Family Termitidae

Includes most of the living termites which are ground dwelling; pronotum of workers and soldiers narrow, with a raised median anterior lobe. e.g. *Odontotermes, Microtermes, Nasutitermes, Capritermes.*

Agricultural Pests

Species of termites that are destriuctive to crops include *Microtermes obesi, Odontotermes obesus* and O. *assumthi.* Sugarcane, wheat, groundnut, coconut, cotton etc. are destroyed by these forms. O. *obesus* and O. *assumthi* affect sugarcane during the planting itself. In attacked plants the outer leaves dry up first. (These could be easily removed at this stage) 40 to 60 per cent of buds are damaged in freshly planted sets. In millable canes five to six internodes will be eaten up and left on ground. Loss of 33 per cent in total yield and of one to four units in sucrose content in juice is recorded. In Madhya Pradesh groundnut is affected and a loss of 8 to 24 per cent of crop is known to occur. *Microtermes obesi* damages roots and stems of jute in North India. In South India O. *obesus* damages coconut seedlings up to the tune of 20 per cent. Besides other crops like cotton, peas, cabbage, cauliflower, tea bushes, castor, teak, chillies, maize, sorghum, wheat and paddy are also damaged.

Control

Application of an emulsion of chlorpyrifos 20% EC or lindane 20% EC (5 litres in 1500 of water) over the sugarcane setts in furrows at planting affords protection against termites damage in the field. For control of termites in wheat crop the seed should be treated at the rate of 4 ml of chlorpyrifos 20% EC or 7 ml endosulfan 35% EC per kg seed. If attack is noticed in standing crop dilute 1 litre of endosulfan 35% EC or chlorpyrifos 20% EC in 2 litres of water and mix with 50 kg soil and broadcast evenly in one hectare in rainfed crop. In irrigated crop after application provide light irrigation.

To prevent infestation by subterranean termites, in wood work of buildings ground contact of 40 cm from the ground should be avoided. A thin sheet of metal or good concrete between the foundation and timbers of the house will prevent termite attack. Termite proofing can be done by pressure impregnation with coal tar, sodium fluosilicate, chlrorpyrifos, lindane, etc. after the wood is cut.

Preconstruction treatment is with either chlorpyrifos or lindane emulsion (5 litres of 20% EC formulation to be diluted in 100 litres of water). The foundation pits at the base and the side walls to a height of 30 cm should be treated with the emulsion using a sprayer or water can. The refill earth on both sides of the newly built wall should be treated with the emulsion at 7.5 litres/ sq. m. Before laying the floor, drench the top surface of the consolidated earth within the plinth with the emulsion. Inside the building, drill holes in the floor slab to a depth of 1 cm and 30 cm apart, inject with the emulsion and seal after drying. In the case of mounds, break it open at several places and pour the emulsion.

Chlorpyrifos 1% mixed with resin at mixing stage and used in glue lining at the time of manufacture of plywood affords protection against termite damage.

◆ Chapter 53

Order Zoraptera

This order of insects includes minute, mostly eyeless species less than 3 mm long, living under bark, decaying vegetation, etc. with only a single known genus *Zorotypus.* Available records of distribution indicate that though the number of species are few, they occur in all the regions except the Palaearctic. They are mostly apterous, but macropterous forms with eyes and ocelli have also been known in many species.

The head presents a distinct epicranial suture and bears three-segmented, moniliform antennae. The mouthparts are typically mandibulate, with strong mandibles for mastication, the maxillae and labium normal, with palps five and three-segmented respectively. Wings are easily shed as in the case of termites and the venation is greatly reduced, often approaching the Psocoptera. A pterostigma is distinct as also the radial sector (R_5), while the other main veins are usually unbranched. The abdomen is 11-segmented with a pair of short cerci and an ovipositor absent in the female; the male genitalia distinct, sometimes asymmetrical. There are ten pairs of spiracles, with two pairs thoracic in position and the rest abdominal.

In the alimentary canal, the crop is large and extensive, the midgut an ovoid sac, and hindgut convoluted. There are six rectal papillae and an equal number of malpighian tubules. In the nervous system there are three thoracic and only two abdominal ganglia. The panoistic ovarioles are four to six in number, while the testes are paired ovoid bodies.

◆ Chapter 54

Order Psocoptera

BOOK LICE OR PSOCIDS

The order psocoptera includes minute insects three to six mm long, with or without wings and are popularly known as the book lice, in view of their frequenting the bindings of books and feeding on the glue. In addition to feeding on fragments of decaying animal or vegetable matter, the psocids occur in a variety of habitats such as tree trunks, tree bark, in birds' nests, in straw and chaff, on fungi and lichens. Though not very important from the economic point of view, they can still sufficient nuisance by being present in stored tea, cereal products and flour. They also cause damage to dry specimens in museums. Many of them live in colonies or in clusters particularly on tree bark or within a fine network of silken threads on branches.

The psocids are soft bodied with integument moderately sclerotised, the large head bearing distinct epicranial suture, protruding large compound eyes and long filiform antennae, usually with 13 segments, sometimes with many more segments. Three ocelli are distinct in winged psocids and absent in the apterous forms. An anteclypeus and a postclypeus are distinct sclerites on the head, the labrum being attached to the anteclypeus. The mouthparts are adapted for biting and chewing. The mandibles are large, strong, dentate and with a well developed molar area. The maxillary palp is four-segmented, the lacinia being modified into a 'pick' or a strongly sclerotised rod, sunk into the head and used for scraping and the galea is two-lobed. In the labium, the mentum and prementum are distinct, the paraglossae are large and membranous, the glossae reduced: one or two-segmented. The hypopharynx is well differentiated, bearing superlinguae. Ventrally the surface of the superlinguage is thickened to form two oval sclerites, the lingual sclerites. Also present in association with these sclerites is a median sitophoral sclerite. All these appear to be adaptations concerned with the break up of food particles.

The prothorax is characteristically small, mostly concealed in between the head and mesothorax, in the alate species. In the apterous forms the prothorax is larger. Though the mesothorax and metathorax are distinct and similar, with the typical notal plates, the sternites are very narrow plates. Rarely, however, the tergites and sternites become united to form a continuous structure. The membranous wings, of which the forewings are much larger than the hindwings, possess very prominent, but reduced venation. A pterostigma is very characteristic in the forewing. The costa is marginal, the subcosta unbranched and short, R forming the pterostigma, R_5 branched into two, M many branched and usually there is a fusion of the main stems of M and Cu. Anal area is not present even in the hindwing. The frenal hooks of the hindwing fit into the nodus of the forewing during interlocking. The legs are adapted for running, the coxae being large, and the inner surfaces of the hindcoxae bear a peculiar stridulatory structure in some species. The tarsi bear two claws, the pulvilli distinct and without an empodium. The barrel-like abdomen is mostly nine-segmented with a distinct epiproct and lateral paraprocts. There is a variously developed aedeagus and a pair of lateral arms on each side, often referred to as inner and outer parameres (the inner ones presumably being branches of the outer pair). The ovipositor is small, concealed by the eighth abdominal sternite, and consists of three pairs of valves.

The alimentary canal consists of an elongate oesophagus, foregut without a proventriculus, a curved midgut without caeca and hindgut with six rectal papillae. There are two pairs of salivary glands whose ducts open at the base of the labium. One of these is salivary in function and usually ventral, while the dorsal gland functions as the pinning or silk glands, whose secretion forms the web. The malpighian tubules are four in number. In the respiratory system, there are two pairs of thoracic and seven or eight abdominal spiracles. The nervous system is more concentrated, with a brain, suboesophageal ganglion, a prothoracic ganglion, a usually fused meso- and metathoracic ganglion and a single abdominal ganglion lying far forwards almost in association with the metathoracic ganglion. In the female there are three to five polytrophic ovarioles, the spermatheca globose in shape, opening into the vagina. The paired testes may possess one or more follicles and the vasa deferentia is short and leads into seminal vesicles which are two chambered.

The eggs are mostly laid on the bark either scattered or in groups and generally covered with some encrustation, or laid in silken webs. Some are viviparous, while yet others have facultative parthenogenesis. Metamorphosis involves six nymphal instars, the nymphs appearing like miniature adults, and differing from adults in the absence of wings and fewer number of antennal segments.

SUBORDER TROGIOMORPHA

Tarsi three-segmented, antennal segments without annulations and with more than 20 segments and with two-segmented labial palpi.

Family Trogiidae

Claws not toothed and body and wings without scales. Head short and transverse; maxillary palp usually with a sense organ. E.g. *Lepinotus* and *Trogium* found in granaries.

Family Lepidopsocidae

Body and wings with distinct scales; claws with a preapical tooth. Head and maxillary palps as in Trogiidae. e.g. *Lepidopsocus.*

Family Psyllipsocidae

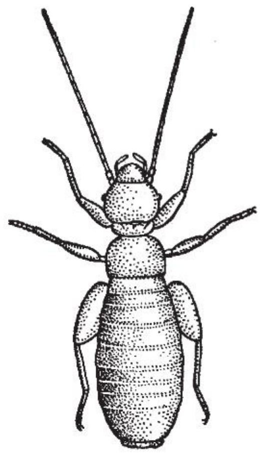
Head not transverse, but long and vertical; antennae with 27 to 46 segments. Maxillary palps without sense organ. e.g. *Psyllipsocus.*

Suborder TROCTOMORPHA

Antennal segments annulate and with 12 to 17 segments; labial palps two-segmented and tarsi three-segmented.

Family Liposcelidae

Body very much flattened with broad (Fig. 54.1) and flattened hindfemora. Wings reduced or absent, meso- and metanota often fused. e.g. *Liposcelis divinatorius.*



▲ **Fig. 54.1** *A psocid Liposcelis (after M.G.R. Menon)*

Family Pachyproctidae

Body mostly convex, hindfemora not flattened, otherwise resembles Liposcelids.

Family Amphientomidae

Wings scaled; forefemora usually with a row of saw-like teeth; forewings with two anal veins.

Family Plaumaniidae

Wings not scaly; forefemora simple.

Suborder EUPSOCIDA

Labial palps with only a single segment; tarsi two- or three-segmented. Antenna mostly with 13 segments. The two more important families are:

Family Psocidae

Tarsi two-segmented; forewings with Cu looped forwards at apex and almost touching or fused with M and $R_{4\text{-}5}$ free from the median vein. e.g. *Stenopsocus* and *Psocus*.

Family Mesopsocidae

Tarsi three-segmented. Forewings with one anal vein. Forewings with tip of Cu curved forwards into a loop and not touching M. e.g. *Mesopsocus*.

◆ Chapter 55

Order Mallophaga

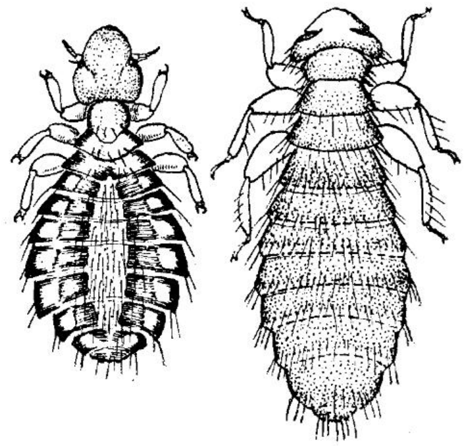
BIRD LICE

The Mallophaga or 'bird lice' are minute, flattened apterous ectoparasites mostly of birds, rarely of mammals, with chewing mouthparts, and subsisting on hairs or feathers, skin, scales or dried blood from scales (Fig. 55.1).

The head is flattened from top to bottom and its long axis is on the same plane as the body. The tentorium is reduced. Many of the sutures of the head capsule are obliterated, the clypeofrontal suture distinct. The labium is pouch-like and the maxillae and labium are reduced to simple lobes without palps in the Ischnocera and with two- to four-segmented palps in the Amblycera. The short antennae usually with three to five segments, also vary in the two suborders. The antennae are filiform, free or exserted in the Ischnocera, while they are short, mostly capitate and lying in a depression in the Amblycera. In the males they may be used as clasping organs. The maxillae consist of a single unspecialised lobe, attached laterally to the labium. The mandibles are well developed and toothed, placed more horizontally or lying parallel with the ventral surface of head in the Amblycera or vertically in the Ischnocera, being almost at right angles to the head. The hypopharynx is peculiar in that it is produced into stylet-like structures for piercing.

The prothorax is narrower than the head, almost free and distinctly separated from the mesothorax. In the Ischnocera, the nota of the pterothorax is united, but separate in the Amblycera, while the meso- and metasterna are also fused. Legs are longer and almost alike and the tarsi bear a pair of well developed claws, or sometimes only one as in the mammalian lice.

The abdomen is eight- to ten-segmented. The reduced ovipositor appears to be represented by a pair of small appendages on the eighth sternite of the female, while in the males there is a median aedeagus.



▲ **Fig. 55.1** *Chicken lice—A. Body louse Eomenacanthus stramineus; B. Head louse Cuclogaster heterographus (courtesy: U.S.D.A., Washington)*

The comparatively short alimentary canal is generally straight, rarely convoluted, with a distinct crop bearing a pair of caeca on either side, well-developed midgut and short hindgut. Four malpighian tubules and six rectal papillae are also present. The crop is more specialised in the Ischnocera being large, spacious and of varied form. Opening at the base of the labium is a pair of labial salivary glands. In addition a pair of salivary glands is located in the thorax, with reservoirs and opens into the anterior part of the gut. The circulatory system consists of a very short heart, situated in the seventh and eighth abdominal segments, with two to three pairs of ostia. In the respiratory system, there is a pair of spiracles on the mesothorax. Six or rarely five or seven pairs of abdominal spiracles are situated in segments three to eight, rarely on three to seven or two to seven. The nervous system is characterised by concentrations of the ganglia, with no abdominal ganglia, the abdomen being innervated from the metathoracic ganglion. The three thoracic ganglia are closely placed, without connections. The brain is large and the suboesophageal ganglion is greatly enlarged.

The ovaries in the females are made up of five panoistic or polytrophic ovarioles, sometimes restricted to only three ovarioles. The unpaired accessory gland which secretes a cement like substance for attaching the eggs is present. The spermatheca often assumes various shapes. The testes are formed of two or three ovoid or pyriform follicles, generally three in the Amblycera and two in the Ischnocera. The ejaculatory duct is coiled and its winding is related to the large, bilobed seminal vesicles.

Habits

The feathers infested are the down feathers and it is interesting that the Mallophaga actually hang on to the barbs of the feathers, with the head foremost and with the aid of the second and third pair of legs, the first pair being used to push the barbules towards the mouth. In view of the food being keratinaceous, protein digesting enzymes help in their breakdown. In some cases certain bacteria are known to be associated with digestion. In addition to feathers, only some of the Amblycera take to blood-serum feather diet. *Eomenacanthus,* the lice attacking chicken, has a mixed diet of feather and hair, puncturing the young feathers with the mandibles and drawing blood from the pulp, in addition to getting blood through gnawing the host's skin. Some are known to live attached to the inner walls of the throat pouches of cormorants and pelicans, feeding on blood and epithelial debris.

The movement of Mallophaga is also varied according to their habitat. For instance the narrow, elongate species moving very fast on the longer feathers of the body and wings, the short and round forms on the head and neck moving slowly. The legs in the Amblycera which move on the general surface and feathers, have a larger tarsus, while the Ischnocera are adapted to clinging to feathers by shortened tarsi and paired tarsal claws.

The life cycles are spent on the body of the host. The females are larger than the males. In the common pigeon louse *Columbicola columbae* the eggs are pearly white, laid in rows along the grooves between barbs and are attached or glued to the feathers by a cement-like substance secreted by the accessory glands of the female. The eggs are also laid on the feathers of the head and neck singly or in clusters. A distinct operculum is present in the egg and the eggs are finely sculptured. The nymphs hatching out look just like the adults in appearance, moult thrice, each nymphal stage lasting 6 to 7 days and the length of the life cycle varies with the temperature of the host.

Astonishingly large numbers of Mallophaga have been recorded on several hosts with a normal number of over a 1000 to a maximum recorded number of over 7000 in cormorants. When in large numbers they can cause intense irritation with loss of feather shafts and loss of blood during feeding. Some correlation also exists between the colour of the lice and the colour of the host.

Well marked host specificity is normally exhibited by Mallophaga and plurality of hosts is rare and mostly brought about by close contacts with hosts and use by the different hosts of the same huddling place by the different hosts and also through human intervention. The texture of the feathers of the hosts and the chemical constitution of the plumage of the atypical host, prevent Mallophaga from leaving their hosts. The most notable example of parasites from other birds is seen in the domestic fowl *Gallus domesticus.* The common house sparrow *Passer domesticus* has as ectoparasites *Philopterus fringillae* and *Brueelia subtilis.* The domestic fowl is infested by about four Amblyceran and ten Ischnoceran parasites such as chicken body louse *Eomenacanthus stramineus*, *Menacanthus pallidulus*, *M. cornutus*, chicken louse *Menopon gallinae* (Amblycera), chicken fluff louse *Goniocotes gallinae,* chicken brown louse *G. dissimilis,* large hen louse *Goniodes gigas,* tropical hen louse *Lipeurus tropicalis*, chicken wing louse *L. caponis*, chicken head louse *Cuclogaster heterographus* (Ischnocera). The peacock is infested by *Lipeurus pavo* and *Goniodes pavo*, both Ischnocera, and *Goniocotes mayuri*, *Amyrsidia minuta* and *Colpocephalum thoracicum* among the Amblycera. The goat lice *Damalinia caprae* infests by chewing hairs, feathers, downs and scales of epidermal tissues of goats in India.

Suborder AMBLYCERA

Antennae four-segmented, capitate, concealed. Mandibles more horizontal, maxillary palp four segmented, Meso- and metathorax usually separate. Some of the important families in this suborder are given below.

Family Menoponidae

Infesting birds. Head broadly triangular, much enlarged at temples and evenly expanded behind. *Menopon gallinae*, the domestic fowl louse; *Eomenacanthus stramineus*, the poultry louse.

Family Laemobothridae

Infesting aquatic birds. Head not enlarged at temples and not evenly expanded behind. e.g. *Laemobothrion.*

Family Gyropidae

Ectoparasitic on rodents. Legs generally modified for clasping. *Gyropus ovalis* on guinea-pig.

Family Boopidae

Infesting mammals. Occurs in Australia, ectoparasitic on marsupials like kangaroos. Legs long and slender and body clothed with stiff, slender spines. e.g. *Boopia* and *Heterodoxus.*

Family Ricinidae

Ricinus is ectoparasitic on song-birds and *Trochilocoetes* on humming-birds.

Family Trimenoponidae

Members of this family have been reported to infest marsuspials and rodents in S. America.

Suborder ISCHNOCERA

Antennae three- to five-segmented, filiform; mandibles vertical and without maxillary palps, meso- and metathorax generally fused.

Family Trichodectidae

Parasitic on domestic mammals. Antennae 3-segmented. *Trichodectes bovis* on cattle, *T. ovis* on sheep and *T. canis* on dogs.

Family Philopteridae

Very widely distributed family occurring on birds. Antennae five-segmented; last antennal segment being cylindrical. e.g. *Anatoecus, Brueelia, Degeeriella, Philopterus, Goniocotes, Columbicola, Goniodes.*

Family Bovicolidae

These are ectoparastic on horses, bovids, deers and camels. e.g. *Bovicola, Damalinia.*

Family Dasyonygidae

These occur on hyraxes.

Family Trichophilopteridae

Species of *Trichophilopterus* occur on lemurs.

Suborder RHYNCHOPHTHRINA

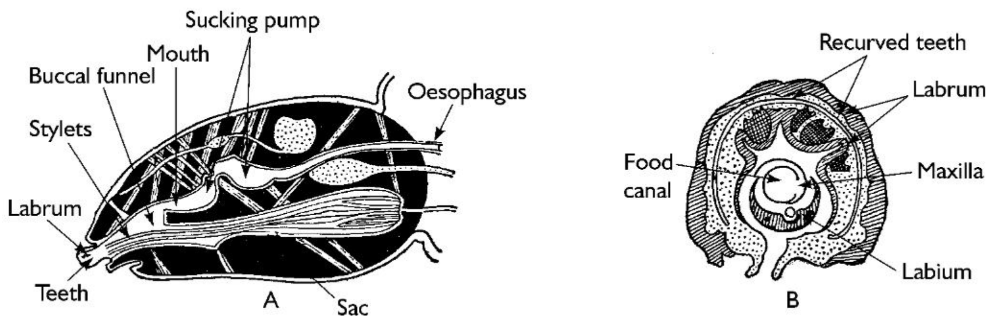
Head prolonged into a rostrum and mandibles are present at apex of rostrum are present. Represented by a single family Haematomyzidae which occur on elephants. *Haematomyzus elephantis* is found in India on elephants.

◆ Chapter 56

Order Siphunculata

SUCKING LICE, ANOPLURA

The members of this order include small, wingless, tough-skinned, dorsoventrally flattened, often dark-coloured insects, ectoparasitic on all kinds of wild and domesticated mammals and man. They live exclusively by sucking the blood of the host and are called the sucking lice (Fig. 56.1).



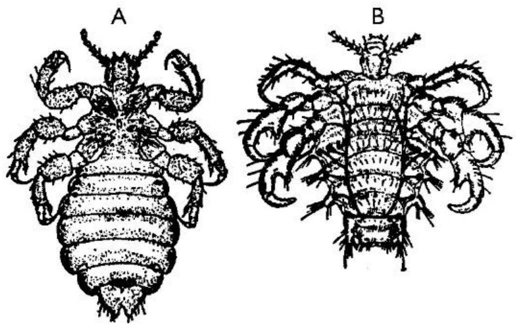
▲ **Fig. 56.1** *The piercing and sucking apparatus of Anoplura. A. Section of head showing buccal and pharyngeal pumps, B. Section of the labrum and piercing stylets (Snodgrass, 1935)*

The head is prognathous, small, freely movable, without ocelli, with vestigial or moderately developed compound eyes and short, thick antenna composed of three to five segments. The mouthparts are adapted for piercing and sucking, with a short proboscis or rostrum armed with minute denticles inside. The rostrum which is the piercing organ is exserted while feeding to have a grip or hold on the host. The cibarium and pharynx together form a powerful licking pump; lying ventrally to the cibarium is a distinct pouch within which are three stylets, two dorsal and one ventral, the dorsal ones joining to form a food tube. Through the ventral middle stylet, saliva is injected. The contraction of the muscles of the cibarium and pharnyx helps in the drawing in of blood. Palpi are generally absent (Fig. 56.2)

The thorax is short, without distinct segments; and sclerites undifferentiated, legs short, stout and adapted for clasping or grasping with the aid of a long claw at the end of the one-segmented tarsi which work against tibial processes. The claw is useful in clinging to hairs of the host.

The abdomen is distinctly segmented and the pleurites appear more sclerotised and pigmented than the tergites and sternites. Cerci are absent in both sexes. For purposes of grasping the hair during oviposition and for arranging the eggs, the females possess a pair of gonopods, while in the males, a well developed copulatory structure is present.

The alimentary canal is simple. It has a crop and an undifferentiated gizzard. The stomach is large and in *Pediculus* with two enteric caeca. Four malpighian tubules are present. The rectum bears six sclerotised rectal papillae. Along with two pairs of well developed salivary glands which opens into a common salivary canal, there are a pair of specialised glands called Pawlowsky's glands which open into the stylet sac. In the respiratory system there are seven pairs of spiracles, six pairs on the abdominal segments of three to eight and a mesothoracic pair placed dorsally.



▲ **Fig. 56.2** *A. Pediculus humanus capitis, B. Phthirus pubis*

In the males, the testis is bilobed and compact and leads into very slender vasa deferentia. In the females the ovaries are made up of five polytrophic ovarioles. Accessory glands are distinct, opening into the oviducts. In the nervous system, the thoracic and abdominal ganglia are fused to form a compact mass.

Family Echinophthiriidae

Body stout, invested with thick setae, occasionally modified with scales, with a pair of spiracles on metathorax. Found on marine mammals.

Family Phthiridae

Forelegs more slender than others; abdominal segments three to five fused and with three pairs of spiracles. *Phthirus pubis,* the pubic or crab louse of man.

Family Pediculidae

All abdominal segments are free, with spiracles; similar forelegs, e.g. *Pediculus humanus*, the louse on man; there are two subspecies–*P. humanus capitis* smaller and darker with stout antennae occurring on the human head, and the body louse *Pediculus humanus vestimentorum* which is the vector of relapsing fever.

Family Haematopinidae

Sometimes with indistinct tergal and sternal plates and found on ungulates, dogs and rodents. e.g. *Haematopinus tuberculatus*, the buffalo louse; *H. quadripertusus,* the cattle tail switch louse; *H. suis,* the hog louse on swine; *Linognathus setosus*, the dog louse; *L. stenopsis* and *L. africanus,* the goat lice; *L. viruli,* the calf louse.

Family Hoplopleuridae

They occur mainly on rodents. e.g. *Polyplax, Hoplopleura, Haemodipsus. Haemodipsus ventricosus* occurs on rabbits.

Family Linognathidae

Linognathus occur on sheep, goats and cattle.

Family Neolinognathidae

Characterised by one pair of spiracles on eighth abdominal segment. Two species are so for known infesting Macroscelidid insectivores.

Pediculus humanus is of medical importance because it is the vector that transmits main disease agents, apart from causing local irritation and inflammation. *Rickettsia prowazeki*, the causative microorganism for the typhus fever, multiplies in the gut of a louse. The louse ingests the microorganism while feeding on the blood of an infected person. While a louse is crushed, infection results even if there is a small abrasion of the skin. Transmission does not occur while feeding. Other forms of typhus disease or rickettsial disease are also caused by *Pediculus humanus. Spirochaeta recurrentis*, the spirochaete responsible for relapsing fever in man is carried in the haemolymph of the body louse and enters the human system through skin abrasions when the louse is crushed.

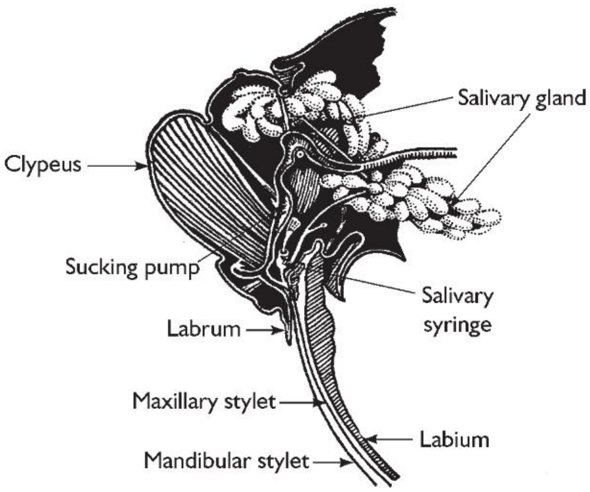
Lice carry symbiotic micro-organisms in special organs called mycetosomes located in the foregut and ovaries. These appear to be essential to the life of the lice and it has been shown that amputation of the gut mycetome make the lice unable to feed. It has been demonstrated that if the progeny of head lice are kept under environmental conditions similar to those of the body lice, they become gradually transformed and become indistinguishable from the body lice in the course of several generations. Perhaps this ability to differentiate in either direction is an adaptation to adjust themselves to local conditions. The possibility of the proportions of the two kinds of cytoplasmic particles of symbionts changing according to the environment, has also not been ruled out.

◆ Chapter 57

Order Hemiptera

BUGS

The Members of this order, commonly referred to as bugs, vary greatly in size from extremely small individuals to those measuring about 110 to 140 mm. They are mostly terrestrial, some are aquatic or semi-aquatic. They are widely distributed throughout the world but abundant in tropical regions. The most distinctive feature of the Hemiptera is the piercing and sucking mouthparts by which they are easily recognized from other insects. However, the mouthparts are atrophied in the males of Coccoidea.



▲ **Fig. 57.1** *The sucking pump and salivary syringe of Magacicada septendecim. Section showing cibarium with dilator muscles arising on the clypeus (Snodgrass, 1935)*

Bugs possess usually two pairs of wings with the anterior pair of a harder consistency than the posterior pair. The later slightly shorter than the forewings. In the Homoptera (Fig. 57.1) both the pairs of wings are of uniform texture whereas in the Heteroptera the apical portion of the forewings is more membranous. The presence of a distinctive scutellum between the base of the wings is also characteristic of the order. In most cases the body is broad and flattened dorsoventrally. Metamorphosis is gradual or incomplete.

The Hemipterous insects are generally sap feeders of crop plants and trees, and a large number of them are agriculturally very important as potential pests. A few members of Homoptera are very important as vectors of virus diseases. Most bugs possess an unpleasant odour which affords protection to them from natural enemies. Certain hemipterous insects show close resemblance to insects of their own or other orders. The brachypterous individual of the coreid bug *Dulichius inflatus* resembles closely the ant *Polyrachis spiniger* and also associates with it. Similarly, in England the nymph of the coreid *Alydus calcaratus* resembles the ant *Formica rufa.*

Head

The head is inclined variably to the longitudinal axis. In most Heteroptera it is porrect whereas in the Homoptera it is deflexed. The sclerites in the head are fused and compact. The presence of a frons can be noticed only in some psyllids and in cicadids, in which it bears a median ocellus. A large post-clypeus and a small ante-clypeus constitute the clypeus. In the auchenorrhynchan Homoptera the post-clypeus is swollen and conspicuous, whereas in Heteroptera it is not well marked.

The mouthparts are of the piercing-sucking type formed of a narrow and acuminate labrum, a slender segmented beak, and the labium, which encloses the four stylets. The beak may arise from the front part of the head as in the Heteroptera in which case it usually extends back along the ventral side of the body, sometimes as far as the base of the leg. It may also arise from the posterior part of the head as in the Homoptera. The four stylets enclosed by the segmented grooved labium are formed of the mandibles and the maxillae, the inner maxillary stylets being closely interlocked together to form an anterior food channel and a posterior salivary channel. The labium or beak may be four-segmented as in Pentatomidae, Lygaeidae, Miridae, etc. or three-segmented as in most Reduviidae, Cicadidae, Aleyrodidae and Psyllidae, or one- or two-segmented as in Coccoidea and Corixidae. Maxillary and labial palpi are wanting.

In many Homoptera the stylets are sometimes extremely long, often exceeding the length of the body. Similar condition is also seen in a few mycetophagous Heteroptera of the family Aradidae. In such cases, the stylets are looped or coiled and withdrawn into a pocket connected with the channel of the labium. In Coccoidea the pocket lies in between the central nervous system and the ventral body wall lined by a thin membrane and is known as the crumena. While feeding, in aphids, the stylets reach the phloem vessels intracellularly whereas in the leaf-hoppers they pass through the cortical cells. Saliva injected while piercing the tissue reacts with the plant sap and a tubular sheath around the stylets is formed. Extra-intestinal digestion is also possible with the help of enzymes in the saliva. The sap is withdrawn into the alimentary canal by the action of the cibarial sucking pump of the insect.

A pair of well-developed eyes are present. Ocelli are usually two as in Heteroptera and most Auchenorrhyncha, or may be three as in many Sternorrhyncha and Cicadidae, or may be wanting as in Cimicidae, Pyrrhocoridae, some Cicadellidae and most Cryptocerata. Supplementary eyes or ocular tubercles are found in many aphids close to the compound eyes. Antennae are generally four- or five-segmented or may be 10-segmented as in psyllids or 25-segmented as in the males of a few coccids.

Thorax

In the Heteroptera the pronotum is uniform, the mesonotum is composed of a number of sclerites of which the scutellum is very prominent, and the metanotum is very variable. In the Homoptera the pronotum is small except the Membracidae in which it attains incredibly fantastic and grotesque forms, extending backwards over the abdomen. The mesothorax is large and the metathorax is well developed.

Wings

The forewings or hemelytra of heteropterous insects are characterised by the proximal area being well-sclerotised and the smaller distal portion being membranous. The hindwings are always membranous and are folded beneath the hemelytra. The wings are held flat over the abdomen at rest. The structure of the wings exhibit lot of variations and hence they are of taxonomic importance. In a hemelytron two regions, viz. an outer broader corium and inner narrower clavus, are recognised, separated by a concave vein Cu_2 in the hardened proximal or basal portion as in Lygaeidae. In anthocorid bugs a narrow strip, demarcated from the corium towards the costal margin and from the remainder by R+M, is referred to as *embolium.* A triangular apical portion of the corium called *cuneus* is present in Miridae and Velocipedidae. In Gerridae and Tingidae the differentiation may be less distinct.

Homopterous insects possess uniform textured wings, the forewings being of harder consistency than the hindwings. The parthenogenetic forms as well as sexuales of aphids and the females of coccids are apterous. Winged or wingless males may be noticed sometimes in aphids and coccids. Alary polymorphism, i.e. possession of two or more forms of alary organs in the same species with or without any correlation to the sex, is noticed in different families of Hemiptera such as Gerroidea, Anthocoridae, Reduviidae (Heteroptera), certain Fulgoroidea (Delphacidae) and Cicadellidae (Homoptera). The individuals may be apterous and macropterous, sometimes with brachypterous forms. This phenomenon is attributed to climate, season, mimicry, rapid locomotion and mode of life.

Abdomen

The abdomen is 11-segmented. In Cicadidae the first two segments are modified for sound production. The number of well-defined segments may be reduced frequently. In Psyllids the first three-segments are suppressed or greatly reduced. Segmentation is obscure in aphids and in the females of coccids. The cerci are wanting.

The ovipositor is made up of three valves derived from the eighth and ninth sterna in many auchenorrhynchan Hemiptera. Most of the Heteroptera have smaller ovipositor made up of two valves whereas those which insert their eggs into plant tissues possess a well developed ovipositor of three valves. Ovipositor is wanting in aphids and coccids. In the males the external genitalia are developed from the eighth and ninth sterna. In the Heteroptera and Auchenorrhyncha the ninth sternum is enlarged with a pair of lateral claspers. The membrane between the ninth and tenth sterna gets invaginated to form a cavity lodging the median penis and a pair of parameres. In the Psyllidae and Aleyrodidae the claspers are wanting whereas in the Aphidoidea and Coccoidea both claspers and parameres are wanting.

There are ten pairs of spiracles present in most cases, the first and second pairs being located between the pro- and mesothorax and the meso- and metathorax, the third pair between the metanotum and the first abdominal segment and the remaining on the ventral aspect of the consecutive abdominal segments. In the adult aquatic bug *Nepa* sp. the spiracles are either non-functional or closed and in *Notonecta* nine pairs of spiracles alone are present. In the auchenorrhynchan Homoptera ten pairs of spiracles are present. However, variations occur in the sternorrhynchan Homoptera. Aphids possess nine pairs of spiracles, the first two on the pro- and metathorax and the remaining on the first seven abdominal segments. Adult *Psylla mali* has been reported to have two thoracic and three abdominal spiracles. In the Aleyrodidae the third and fourth instars possess four pairs of spiracles, one on either side in the prothorax, metathorax, fourth abdominal segment and the vasiform orifice. In coccid nymphs and adult females there are two thoracic spiracles, the abdominal spiracles being present in certain groups only.

Sound Producing Organs

In Hemiptera, sound production is possible in the following five ways.

1. In many Reduviidae and Phymatidae the prosternal furrow is cross-striated and by working the rugose apex of the rostrum on this ferrow, sound is produced.
2. On either side of the fourth and fifth abdominal sterna of certain Pentatomidae (Scutellerinae) strigose areas are found. Wart-like tubercles, each bearing a subapical tooth, are found on the inner side of the hind tibiae. When the insect rapidly bends the tibiae against the femur and again extends it, the tubercles pass across the strigose areas and produce sound.
3. In males of some Corixidae, there is a spinose area on the inner side of each anteriorfemur, which when drawn over the edge of the clypeus produces sound. It is referred to as pedal stridulating organ.
4. Coxal stridulatory organs are present in *Ranatra*. It possesses two opposing rasps. The one with longitudinal striations are situated, one on each coxa near the base. The other is placed on the inner surface of the cephalic margin of the lateral plate of the coxal cavity. The lateral plate being thin may function as a resonating organ.
5. Dorsal stridulatory organs are found in both sexes of the pentatomid bug *Tessaratoma papillosa*. Close to the metathorax on either side of the dorsal aspect of the abdomen a striated surface or file is situated which produces sound when moved backwards and forwards over the base of the undersurface of the adult wings possessing a comb of strong teeth.

In Cicadidae the sound producing organs are of a complex nature.

Alimentary Canal

At the base of the maxillary stylets is situated the cibarial sucking pump, whose aperture marks the entrance to the alimentary canal. It is followed by a small pharynx, a short oesophagus and the midgut. The midgut shows lot of variations. In Heteroptera the midgut shows an anterior sac-like chamber, a tubular region, an ovoid chamber smaller than the first and a narrow tubular portion with numerous gastric caeca; the fourth tubular region and the gastric caeca may be wanting in predaceous forms. The hindgut constitutes a small bladder-like chamber receiving the malpighian tubules and a very large rectal chamber which in Cryptocerata may possess one or two ampulla-like diverticula. Variations also occur in the number of gastric caeca. They are ten in *Blissus leucopterus*, six in male and none in the female *Dysdercus* and several hundreds in compact packets in *Anasa tristis*. The association of bacteria in the gastric caeca is hereditary, with the bacteria being present even in the gut of the developing embryo.

In many homopteran insects the oesophagus leads into a very capacious crop-like midgut occupying the greater part of the abdomen, the remaining part of the midgut being long and tubular and reflected on the former in an ascending manner. Therefore, the hind intestine also lies alongside the oesophagus in the far anterior aspect and the malpighian tubules are seen in the thorax. A well-developed filter chamber is seen in the membracid *Tricentrus albomaculatus*. The excess water from the wall of the oesophagus and crop would pass into the midgut by osmosis and from there into the hind intestine. Filter chamber is wanting in the Coleorrhyncha and some aphids. Malpighian tubules are generally four in number in Heteroptera but only two in *Lethocerus*. In the Homoptera they are variable in number with four in membracids united proximally in pairs and two in coccids in general. They are wanting in aphids. Salivary glands vary from two to three pairs.

Rectal pads are present in several Heteroptera and have been defined as consisting of a distinct area of the rectal wall with large cuboidal or columnar cells with large nuclei and rich tracheations. Rarely, as in *Aspongopus janus*, the pad is represented by very large cells distributed throughout the ordinary rectal epithelial cells. Five types of rectal pads are distinguished in Heteroptera. They are essential for water absorption and for the excreta to be retained for a longer time in the hindgut. The nature and position of the rectal pads are correlated with the habits of the bug. In terrestrial plant feeders, it is dorsal, lateral and anterior and highly tracheated. In blood sucking bugs, it occupies the anterior part of the rectum and the cells are longer than in plant feeders. In aquatic bugs, it is confined to dorsal and lateral walls of the ileum and extends up to the junction of the ileum and rectum.

Odoriferous or repugnatorial glands are characteristic of a large number of bugs. In most Heteroptera they open to the exterior near the coxae of the hindlegs by means of ventral pores or slits.

Reproductive System

Each ovary consists of a variable number of ovarioles. Spermathecae and two or three tubular or globose accessory glands are present, but are wanting in Diaspididae. Male organs also show variability. In the Heteroptera the testes usually comprise seven follicles. The vasa deferentia at some point are swollen to form the seminal vesicles. Accessory glands range from one to two pairs. In the Homoptera it may consist of a single follicle as in coccids or four or five in Psyllidae, lying free or united in a common sheath. Accessory glands are present. Part of the ejaculatory duct in aleyrodids and psyllids is modified to form a sperm pump.

Other Systems/Organs

Wax glands: They are present in many Homoptera such as coccids, aphids and aleyrodids in the form of powdery secretion or of dense flocculent threads.

Nervous system: Thoracic and abdominal ganglia are fused together to a large extent. There are three ventral ganglia in *Lygaeus*, *Notonecta*, etc., two in aphids and a single one in coccids.

Dorsal vessel: There is mostly a five-chambered heart as in *Lethocerus* and others have four or five chambers and about three or four pairs of ostioles. In the Auchenorrhyncha and Psyllidae a well developed heart is seen which extends over six or seven segments. It may be absent as in some aphids (*Eriosoma*) and some coccids (Diaspididae).

Pulsatile Organs: Aquatic forms possess pulsatile organs in each pair of legs. Among Cryptocerata, the anterior legs have pulsatile organs at the base of the first tarsal segment and the remaining pairs at the base of tibia.

Mycetomes: In most Homoptera, symbiotic bacteria or yeasts are harboured in specialised cells called mycetocytes which occur scattered in the gut wall or fat body as in coccids. Such cells are more often grouped into definite organs known as *mycetomes*.

Metamorphosis

Though the eggs of Heteroptera show lots of diversities in form, structure and colour they possess distinct features characteristic to different families and hence are of taxonomic value. However, among Homoptera the eggs are ovoid and simple. In Aleyrodidae and Psylla a filamentous stalk or prolongation is found at one end. Viviparity has been reported in Polyctenidae and among parthenogenetic aphids. Oviparity, ovoviviparity and viviparity are noticed in coccids.

Metamorphosis is gradual in Hemiptera. Significant change occurs after the last nymphal moult which gives rise to the adult. The number of instars (including the adult) is generally six.

In the Homoptera the numbers of instars are six as in *Psylla* and *Empoasca*, five in aphids, four in aleyrodids and apterous Phylloxeridae, seven in *Cicada* and three in female and four in male coccids. A pupal stage is evident in the males of coccids and in both the sexes of aleyrodids.

Hemiptera is represented by the two distinct orders—Heteroptera and Homoptera. Here, however, the earlier grouping of the rostrum-bearing bugs is retained as Hemiptera

(Rhynchota). Two suborders are distinct Heteroptera and Homoptera. Heteroptera are characterised by wings overlaping the abdomen, the rostral base which is not connected to precoxae, gular portion that is sclerotised, and the three-segmented tarsi. Homoptera have sloping wings over the abdomen, many forms are also wingless, rostral base connected to forecoxae, gular region absent or if present, membrane-like, and one to three jointed tarsi.

Suborder *HETEROPTERA*

Three series viz. Geocorisae, Amphibicorisae and Hydrocorisae are recognised here representing the families respectively of terrestrial, semi-aquatic and aquatic groups.

Series 1. *GEOCORISAE*

Mainly terrestrial species with longer antennae and gula with rostral groove. Legs not modified for swimming.

Section I. *CIMICOMORPHA*

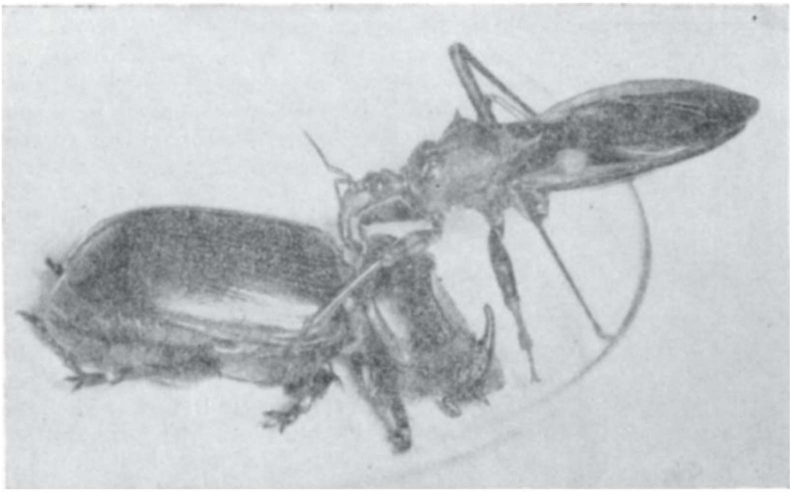
Characterised by four-segmented antennae; the eggs are usually operculate and implanted in substrate. It includes four superfamilies viz. Reduvioidea, Cimicoidea, Dipsocoroidea and Tingoidea. The following are some important families in this section.

SUPERFAMILY *REDUVIOIDEA*

Family *Reduviidae* (*Assassin bugs*)

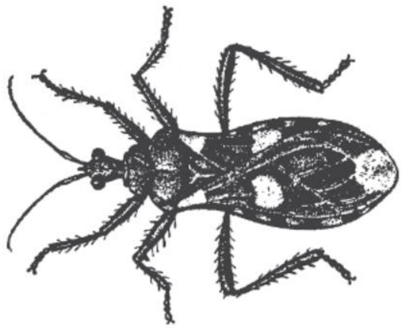
Members of this family are fairly common, usually brownish or black and medium sized to large insects. It has an elongated narrow head, the portion behind the eyes being neck-like. The rostrum is three-segmented, usually curved and its tip fits in a prosternal groove. The antennae are filiform. Metathoracic scent glands are absent. The abdomen is broad at the middle and the margins of the segment beyond the wings are exposed. They are mostly predaceous on other insects and a few are blood suckers. The bite inflicted by these bugs will be painful.

The causal agent *Trypanosoma cruzi* of human trypanosomiasis in South America is carried by *Triatoma* species and *Rhodnius prolixus*. In Madagascar and South Asia the nymphs of *Triatoma rubrofasciata* are found partially concealed under floor debris inside houses. Insect bites of the same can cause severe illness lasting several days in hypersensitive individuals. In India *Harpactor costalis* is predaceous on the red cotton bug *Dysdercus cingulatus. Reduviolus* sp. is predaceous on the mirid *Calocoris angustatus* on sorghum. *Acanthaspis siva* is an enemy of the honeybee *Apis cerana indica* in Coimbatore. *Platymeris laevicollis* (Fig. 57.2) is predaceous on the coconut beetle *Oryctes rhinoceros.*



▲ **Fig. 57.2** *Platymeris laevicollis feeding on Oryctes rhinoceros (courtesy: V.P. Rao)*

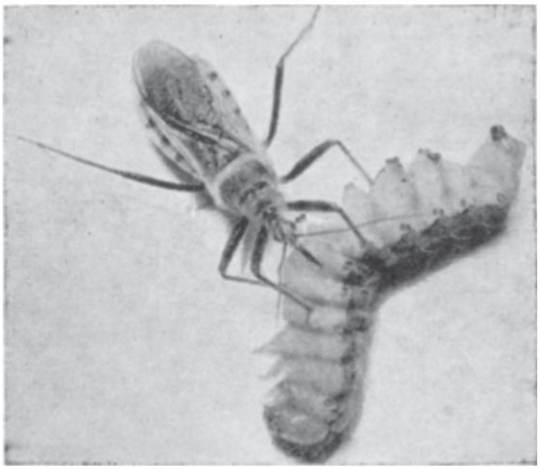
1. *Acanthaspis siva* (Fig. 57.3): Both nymphs and adults freely lurk around the hives, in crevices or in cracks, in tree trunks near the locations of the nests of the Indian bee. They pierce the body of the workers and suck the body liquid. The adult bugs are active during September to November. The small spherical brownish eggs are laid singly in crevices on the hive stands or over moist or decaying leaf moulds accumulated in the vicinity. Incubation period varies from 17 to 28 days. The newly hatched out nymph is pale red. It passes through five nymphal instars. The total nymphal period varies from 107 to 186 days.



▲ **Fig. 57.3** *Acanthaspis siva*

The longevity of male and female is 202 and 115 days respectively. Frequent cleaning of the baseboards of the hives, hive stands and the surroundings of apiary help in keeping away this bug from attacking honeybees.

2. *Rhinocoris fuscipes* (Fig. 57.4): It is predaceous on larvae of *Helicoverpa armigera, Spodoptera litura, Semiothisa pervolgata, Eurema hecabe* and *Catopsilia pyranthe*, and beetles



▲ **Fig. 57.4** *Rhinocoris fuscipes feeding on Helicoverpa armigera (courtesy: V.P. Rao)*

Henosepilachna vigintioctopunctata and *Raphidopalpa foveicollis*. It lays about 45 to 80 elongated, cylindrical, olive coloured eggs in batches varying from 5 to 21. The incubation period is six to seven days. The nymphal period ranges from 30 to 50 days.

SUPERFAMILY CIMICOIDEA

Family Cimicidae (bed bugs)

Members of this family are blood-sucking ectoparasites on man and animals. They are broadly oval, flattened insects having very short hemelytra. Ocelli are wanting. The rostrum lies in a ventral groove. Legs are normal with three jointed tarsi. There are two common species of bed bugs which come under the genus *Cimex*. *Cimex lectularius* is the common bed bug of temperate regions, but occasionally found in the tropical zones. In India it is found in Uttar Pradesh (Dehra Dun) and Jammu & Kashmir. *Cimex hemipterus* (C. *rotundatus*) is distributed in Africa and Southern Asia. The bed bugs are nocturnal and hide during day time in crevices found on walls, floors or furniture in houses. The saliva introduced by its bite causes itching, burning and swelling. The bed bug has not been shown to be a regular disease carrier. The eggs are laid numbering about 75 to 600 in crevices. Incubation period is 6 to 17 days. Nymphal period is about one or two months. Adult longevity is 4 to 12 months. The bed bug is known to transmit Kala-azar.

Other species of *Cimex* are parasites of bats and birds. In North and Central America, *Haematosiphon inodorus* is ectoparasitic on poultry. *Cimex himalayanus, C. inseutus* and *C. usingeri* have been reported to infest respectively the bats *Myotis siligorensis, Rousettus leschenaulti* and *Rhinolophus rouxi* in India.

Family Polyctenidae (bat bugs)

These bugs possess four-segmented antennae; compound eyes and ocelli are wanting; rostrum is three-segmented; forelegs are short with thickened femora and the middle and hindlegs are long and slender with four-segmented tarsi. Hemelytra is of uniform consistency but devoid of membrane. They are ectoparasitic on tropical bats and live deep in the fur of bats belonging to the genera *Megaderma, Taphozous* and *Cynopferus.* These bugs are characterised by the possession of ctenidia, i.e. one or more combs of short flat spines. The insects reproduce viviparously.

Family Anthocoridae (flower bugs; minute pirate bugs)

There are small predaceous insects, elongate oval and flattened. They possess ocelli, three-segmented rostrum, distinct cuneus and embolium, scent gland on metathorax and three segmented tarsi. *Anthocoris kingi* bites man occasionally. Some live in ant's nests and a few in bird's nests. *Piezostethus* sp. is predaceous on sugarcane mealy bugs in Karnataka State. *Orius tantilus* is a common predaceous anthocorid in India which attacks the aphid, *Aphis gossypii*, nymphs of mites on crops and thrips on sorghum ears. *Orius indicus* is predaceous on the thrips, *Megalurothrips distalis* infesting flowers of *Cajanus cajan.*

Family Miridae [Capsidae] (leaf bugs or plant bugs)

These are delicate, small to medium sized elongate insects. Antennae and rostrum are three segmented. Ocelli are wanting. The tarsi are three-segmented. It has a distinct cuneus and an indistinct embolium. A well developed ovipositor is present in female. These insects are variously coloured.

Mirids are primarily plant sap feeders; a few are, however, predaceous on other insects and mites. Some of the important plant pests species in India are: *Calocoris angustatus* and *Megacoelum stramineum* on sorghum ears, *Pachypeltis politus* on betel vine; *Helopeltis antonii* on cashew, cacao, guava, *Azadirachta indica,* tea, grapevine etc.; *Ragmus importunitas* on *Crotalaria juncea*; *Prodromus subviridis* on banana; *Cryptopeltis crassicornis* on tobacco and tomato; and *Carvalhoia arecae* on arecanut. A species of *Psallus* is predaceous on the thrips *Megalurothrips distalis* infesting flowers of *Cajanus cajan*.

1. THE SORGHUM EARHEAD BUG *Calocoris angustatus*

The insect was first noticed in 1891 in South Arcot district (Tamil Nadu) and since then has earned considerable notoriety as one of the most destructive pests of sorghum. It causes serious damage to irrigated sorghum crop during April–June and to a less extent to rainfed crop during August–January. The bugs infest as soon as the ears emerge out of the leaf sheath and within a short period the population increases. Both the nymphs and adults feed on sap of developing grains and grain formation is often entirely ruined. It causes 15 to 30 per cent loss in yield. Compact types of ears show a higher infestation. Another species *Megacoelum stramineum* occurs in association with the sorghum earhead bug and infests the plant, feeding on the sap of developing grains.

Life history: The female by means of its long ovipositor inserts the eggs under the glumes or into the middle of the florets. It lays about 150-200 eggs in about 14 days, 1 to 16 eggs in each floret. The egg is blue, cigar-shaped and the top is closed by a lid fitting into a raised rim. The incubation period is about ten days. The life history from egg to adult occupies 15 to 17 days and there may be at least two generations on one crop of sorghum.

Host plants: *Sorghum vulgare, Eleusine coracana, Pennisetum typhoideum, Zea mays, Setaria italica,* sugarcane *(Saccharum officinarum), Eragrostis abyssinica, Dinebra retroflexa, Dicanthium annulatus, Panicum repens* and *Sporobolus coromandalianum*.

Natural enemies: A reduviid bug *Reduviolus* sp. and a lygaeid bug *Geocoris tricolor* are predaceous on the insect.

Control: Two applications of dusts of carbaryl 10% or quinalphos 1.5% at 10 days interval synchronizing with the milky stage of the crop has been found effective.

2. THE ARECANUT MIRID BUG *Carvalhoia arecae*

Distribution: South India (South Karnataka & Kerala).

Damage: The adults and nymphs suck sap from tender parts and tender leaves of arecanut palms. The bugs remain clustered together within the top-most leaf axils. For feeding they move out and later return to the axils again. At the site of feeding a longitudinal, narrow, decolourised zone develops rapidly on either side of the puncture, along the length of the leaf blade. The decolourised patch gradually turns yellowish, then brownish in a few days and dries up. In this way the tissues may break away leaving holes on the leaves. In cases of severe infestation the leaves get shredded, stand erect and the trees become stunted.

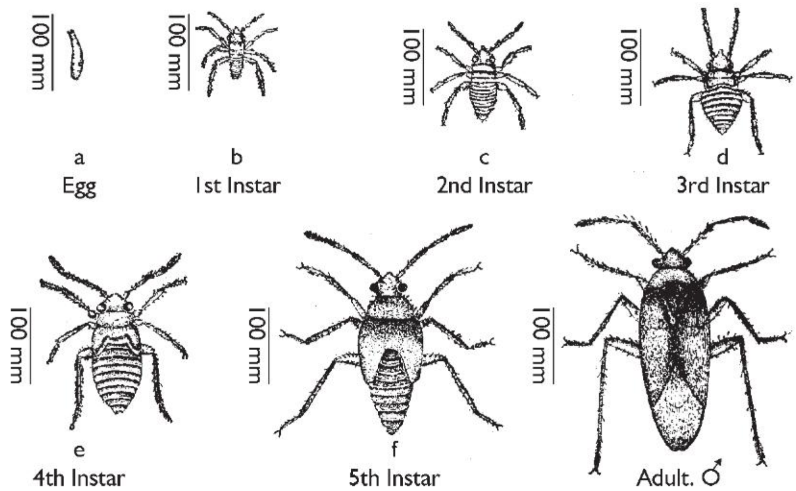
Life history: The female thrusts the eggs individually into the tissues of the tender, unopened leaves of the palm, and rarely two or three eggs are found laid together. The operculum of the egg is visible with two silvery filaments projecting out. The egg is oval, 1.36×0.34 mm and two bristle-like structures arise from the operculum, one being straight and the other curved. The incubation period during February is nine days. There are five nymphal instars and the nymphal periods occupy two to three, two to four, three to five, and six to eight days respectively for the first, second, third, fourth and fifth nymphal instars.

Host plants: *Areca catechu*, *A. lutescens* and *Loxococcus* sp.

Control: Application of lindane 6% granule or phorate 10% granule to the inner most two or three leaf axils at 10 grams per palm in March, June, September and December effectively controls the pest. Alternatively the spindles may be drenched with lindane 0.02% emulsion.

3. THE SUNNHEMP MIRID *Ragmus importunitas* (Fig. 57.5)

Distribution: India, Sri Lanka, Java and Celebes.



▲ **Fig. 57.5** *Eggs and development stages of Ragmus importunitas (B. Banerjee and N. N. Kakoti, Indian Journal of entomology, 30, 1968)*

Damage: This is considered to be one of the important pests of the green manure crop, sunnhemp (*Crotalaria juncea*), in South India. In North-East India, it is a serious pest on *Crotalaria anagyroides* grown for soil rehabilitation in the tea estates. The nymphs and adults both suck sap from the leaves. The tender inflorescence axis and the young unopened buds are preferred for feeding. Due to feeding yellow spots first appear, which later coalesce to form bigger lesions. Attacked leaves are frequently undersized, distorted and badly shaped. Young plants succumb to attack and older plants become stunted.

Life-history: Mating of the bugs occurs two or three days after becoming adults usually in sunnhemp plants. The famale makes holes by inserting the stylets into the plant tissue and then inserts the eggs singly in each hole. The pre-oviposition and oviposition periods range from one to two and five to seven days respectively. There are no filaments on the operculum of eggs which occur in most of the mirid bugs. The incubation period is seven to eight days. There are five nymphal instars, the nymphal periods being 10 to 11.5 days. Longevity of adult males and females ranges from 13 to 33 days and 19 to 43 days respectively. The total life cycle of the bug on sunnhemp from egg to adult (including longevity) varies from 35.5 to 62 days. The population of the bug is high during November-December and July-August, and low during April-May on sunnhemp in South India. In North East India, on *Crotalaria anagyroides* it completes its lifecycle in 16 to 24 days. The bug population on the plant is high during April-May, then declines until the following January, and thereafter increases.

Host plants: *Crotalaria juncea*, C. *anagyroides* and *Barleria cristata.*

Natural enemies: The lygaeid bug, *Geocoris tricolor* is predaceous on the mirid bug.

4. THE TEA-MOSQUITO BUGS *Helopeltis* sp.

Distribution: There are two species of *Helopeltis* that attack tea in India. *Helopeltis antonii* is predominant in South India whereas in eastern India *H. theivora* is the most common. *H. antonii* is found in Sri Lanka and South East Asia.

Damage: Nymphs and adults suck sap from the tender shoots and leaves of tea which curl and dry up. In cashew *H. antonii* attacks the inflorescence and tender shoots which dry up. Scab formation on guava fruits is also due to infestation by the bug.

Life history: The adults mate soon after emergence and the female commences egg laying within two days. The female inserts the red eggs in tender shoots of tea plants, in groups of two or more, and hairs from each egg project outside. A female is capable of laying about 500 eggs. The nymphs that hatch out from the eggs suck the sap from tender shoots and leaves. The life cycle is completed in about a month and in a year there may be several generations. Adults hibernate during winter.

Host plants: *Helopeltis antonii* attacks tea, guava (*Psidium guava*) fruits, grapevine (*Vitis vinifera*) fruits, cashew (*Anacardium occidentale*), avocado, *Sweetenia macrophylla* (mahogany), *Azadirachta indica* (neem), cacao, cinchona, pepper, tamarind, cinnamon, apple, etc.

Control: Spray application of malathion 0.1% or endosulfan 0.07% controls the pest.

5. THE PREDACEOUS MIRID BUG *Psallus* sp.

The nymphs and adults are predaceous on the thrips, *Megalurothrips distalis* eq. infesting flowers of *Cajanus cajan* in Delhi. Early instar nymphs of the bug prefer nymphs of thrips, whereas the fourth and fifth instar nymphs of mirids attack adult thrips. The first instar mirid feeds on a single nymph of thrips and occasionally may stab at one, two or more nymphs daily without feeding on them. As many as three to four nymphs of thrips are attacked daily by the second and third instar nymphs of the bug. The fourth and fifth instar nymphs as well as the adults feed on two adult thrips on an average per day.

The mirid nymphs suck the sap from the tip of the abdomen or the prosternal region between the forelegs of the host whereas the adult pierces the body of the adult thrips, occasionally lifting the host, and suck the body fluid.

The bug lays the eggs inside the tissues of tender shoots singly. Occasionally two, three or four eggs may be found together. On the operculum of the egg are present two unequal bristle-like structures which project out. The incubation period of the egg is two to four days. There are five nymphal instars, the first, second, third, fourth and fifth nymphal periods being three to five, two to three, two to four, three to four and four to five days respectively. The development from egg to adult occupies 20 to 21 days.

6. THE POLYPHAGOUS PREDATOR *Stethoconus praefectus* Distant

The nymphs and adults of the mirid bug has been noticed to be predaceous mainly on the tingids *Dulinius conchatus, Urentius euonymous, Cochlochila bullita, Stephantis typica, Tingis buddleiae, Dictyla sufflata, Corythauma ayyari, Telenomia scrupulosa* and *Phenatropis cleopatra.*

The other families included under this superfamily are: Isometopidae and Microphysidae.

Superfamily DIPSOCOROIDEA (Jumping Ground Bugs)

This includes the following two families, viz. Schizopteridae, Cryptostemmatidae in part) and Dipsocoridae (Cryptostemmatidae and Ceratocombidae). These small delicate insects live among moss, dead leaves, etc.

Superfamily TINGOIDEA (TINGITOIDEA)

The following two families are included under this superfamily.

Family Tingidae (lace bugs)

The bugs are easily recognised by their densely reticulate body and wings. Ocelli are absent. The pronotum covers the scutellum. The elevated ridges and sunken membranous oval areas present a lace-like appearance on the head, lateral expansions of the thorax and the wings. Contrary to the lacelike appearance of adults, the nymphs are usually spiny. The lace bugs, which measure about 5 to 6 mm long, infest leaves of shrubs and trees and feed on sap. Due to loss of sap, yellowish spots appear on the leaves and in cases of severe attack they become brown, shrivel and dry up.

In India, a few species are significant since they attack crop plants. In North India, *Monosteira edeia* on *Zizyphus jujuba*, *Urentius euonymus* on hollyhock, *Tingis buddleiae* on the garden hedges *Buddleia asiatica* and *B. madagascarensis* and *Cadmilos retiarius* on sunflower, chrysanthemum, etc. are important. In South India *Monanthia globulifera* on *Ocimum* sp. and *Coleus* sp., *Habrochila laeta* on *Barlaria cristata*, *Phenotropis cleopatra* on *Indigofera* sp. and *Tephrosia* sp., *Stephanitis typica* on coconut, banana and cardamom, *Urentius hystricellus* on brinjal (*Solanum melongena*), *Corythauma ayyari* on Jasmine and *Dulinius conchatus* on *Morinda tinctoria* are some common important tingid pests.

1. THE BUDDLEIA TINGID *Tingis buddleiae*

This lace bug infests the plants *Buddleia asiatica* and *B. madagascarensis* in Agra. Infested leaves crinkle, dry and drop off. The population of the bug is high during November to March. A female inserts about 12 to 50 eggs, generally scattered on the undersurface of the leaf near the side veins and leaf tips. The incubation period of the egg is 10 to 12 days. There are five nymphal instars, the first and last instars moult after three days while the intermediate instars after two days. The entire development cycle is not generally completed on a single leaf. A mirid bug, *Appolodotus* sp., larvae of *Chrysopa* sp. (Neuroptera) and the coccinellid, *Coccinella* sp., are predaceous on the tingid.

2. THE COMPOSITAE TINGID *Cadmilos retiarius*

In Agra, the tingid initially appears during March on *Helianthus annuus* (sunflower) and subsequently infests other garden plants, viz. Gaillardia, daisy, chrysanthemums, marigold, *Vernonia* and *Launea*. The peak incidence is during July and by September the pest disappears. Also it infests the weed *Argemone mexicana*. The eggs are laid scattered mostly on the upper surface of leaves of host plants and in chrysanthemum laid on the undersurface of leaves. They are also laid on the involucre of bracts and in the stems of succulent herbs. The eggs are inserted slantingly into plant tissue leaving the operculum exposed as white or brownish dots. The operculum has a spongy opercular crest and its function has been suggested to be of humidity control. There are five nymphal instars. *Trichogramma* sp. is parasitic on the eggs of the tingid. A mite, *Leptus* sp. (Erythraeidae), is parasitic on the nymphs and adults, and the last instar parasitised nymph gives rise to adults with crinkled wings.

3. THE HOLLYHOCK TINGID *Urentius euonymus*

Urentius euonymus infests the garden hollyhock (*Althaea rosea*) during March to June in Agra and then gets back to Abutilon on which its eggs over-winter. On hollyhock the infested leaves become pale yellowish with the nymphs and adults crowding on the undersurface of leaves. The adult female lays the eggs on the upper surface of leaves and rarely on the lower surface. The eggs are completely buried in the mesophyll, always at an angle to the leaf surface, leaving the operculum exposed. Faecal matter deposited in the vicinity of the eggs appear as minute spots. There are five nymphal instars. The full developmental cycle is completed on a single leaf.

In Coimbatore, the insect infests *Abutilon indicum, Sida cardifolia* and *Chrozophora rottleri*.

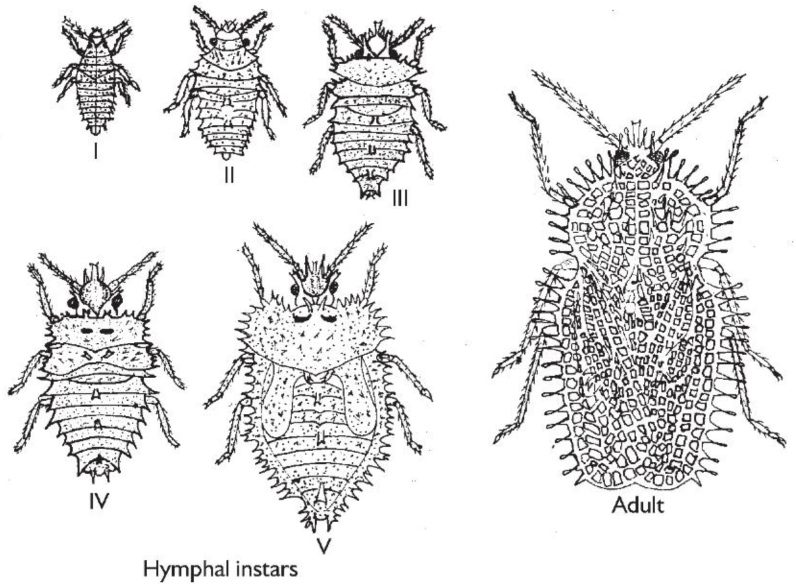
4. THE BANANA LACE-WING BUG *Stephanitis typica* (Fig. 57.6)

It is a pest on foliage of coconut palm, banana, turmeric and cardamom in India. As a pest it has a minor role to play but it causes damage to coconut palms as vector of root (wilt) disease. The immature and adult stages of the bug feeds on the leaf tissue which leaves permanent dechlorophylled yellow marks on the upper surface. On coconut the insect is present in increasing numbers from the outer to the inner leaves

▲ **Fig. 57.6** *Stephanitis typica (Fletcher)* and is more concentrated on the middle leaflets than on either end of each leaf. The bug measures about 4 mm long with transparent shiny reticulated wings and black body. The important predators of the bug on coconut are: *Stethoconus praefectus* (Miridae), *Endochus inornatus, Euagorus plagiatus, Occamus typicus, Rhinocoris fuscipes* (Reduviidae) and *Ankylopteryx octopunctata* (Chrysopidae) and *Geocoris flavipes* (Lygaeidae).

5. THE BRINJAL LACE-WING BUG *Urentius hystricellus* (Fig. 57.7)

Both nymphs and adults cause damage to leaves of the plant. Yellowing of leaves becomes prominent when infestation is heavy. Eggs are thrust halfway into the leaf tissue and a female lays about 75 eggs. Incubation period is five days and life cycle is completed in two weeks.



▲ **Fig. 57.7** *Different stages of Urentius hystricellus (Labh Singh and H.S. Mann, J. Insect Sci., 1995)*

Spray application of methyl parathion 0.025% or methyl demeton 0.025% or dimethoate 0.03% controls the pest.

Section 2. PENTATOMORPHA

Antenna 4 or 5 segmented; eggs not operculate and not inserted in substrate. Six super-families viz. Aradoidea, Coreoidea, Lygaeoidea, Pentatomoidea, Pyrrhocoroidea and Saldoidea.

1. SUPERFAMILY LYGAEOIDEA

This superfamily comprises of five families viz., Lygaeidae, Berytidae, Piesmatidae, Thaumastocoridae and Idiostolidae, of which Lygaeidae is important.

Family Lygaeidae (chinch bug, milkweed bug, etc.)

The lygaeids are small insects conspicuous by their red, white, or black spots or bands. Ocelli are present. The four-segmented antennae are on the sides of the head. The rostrum is four-segmented. Wings are characterised by four or five simple veins in the membrane of the hemelytra. Legs possess rotatory coxae, three segmented tarsi and pulvilli. Thoracic gland openings are evident.

Most of the lygaeid bugs are phytophagous. The chinch bug *Blissus leucopterus* is known to be a most destructive pest of wheat, rye, corn, barley and grasses in America. *Oxycarenus hyalinipennis* is a well-known pest of cotton in all cotton growing countries. Other than O. *hyalinipennis* on cotton, the lygaeids, *Nysius inconspicuous* on gingelly, *Elasmolomus sordidus* on groundnut (*Arachis hypogaea*) and *Pennisetum typhoideum* and *Lygaeus hospes* and *L. militaris* on safflower and sorghum ears are important in South India.

A few lygaeid bugs are predaceous on other insects. In India *Geocoris tricolor* is predaceous on the weevil *Myllocerus viridanus*, the mirid bugs *Calocoris angustatus* and *Ragmus importunitas*, the painted bug *Coptosoma cribraria*, the aphids *Aphis gossypii* and *Aphis nerii*, and the coccids *Pseudococcus* sp. and *Dactylopius nipae*.

1. THE DUSKY COTTON BUG *Oxycarenus hyalinipennis*

This is also known as the Egyptian "cotton stainer." In India it is found in all cotton growing regions. The insect is small and uniform dusky grayish brown in colour. Both adults and nymphs suck sap from immature seeds and stain the lint. The seeds do not ripen and thus get damaged. In Punjab it is known to occur on cotton in considerable numbers during September-October. The female bug lays the cigar-shaped pale yellowish eggs in groups in the lint of half opened bolls, between the calyx and the boll, buds, etc. on plants. The incubation period of the egg is 6 to 10 days. The nymphs moult six times and become adults in 30 to 40 days. The total life-cycle occupies 36 to 50 days. The bug infests cotton, *Abelmoschus esculentus, Hibiscus sabdariffa. Hibiscus cannabinus*, *Althaea rosea, Abutilon indicum* and *Thespesia* sp. The anthocorid bug *Orius tantilus* is predaceous on the nymphs of the bug.

Family Thaumastocoridae (royal palm bugs)

These small insects with broad head are represented in Australia, India, Argentina and Southern Antilles. *Xylastodoris luteolus* infests the royal palm *Oredoxa regia*.

Superfamily PYRRHOCOROIDEA

This includes two families, the Pyrrhocoridae and Largidae, of which Pyrrhocoridae is important.

Family Pyrrhocoridae (red bugs, stainers)

The insects are generally brightly coloured with red and black markings. The body is elongated and oval in shape. They are distinguished from the lygaeids by lack of ocelli and possession of more branched veins and cells in the hemelytra. The rostrum is four-segmented. Glands open in the metathorax. The legs possess rotatory coxae, three-segmented tarsi and pulvilli.

The pyrrhocorids are phytophagous. The species of *Dysdercus* are known as "cotton stainers" as they pierce the bolls and make them vulnerable for contamination by the fungus *Nematospora* which stains the lint. *Dysdercus cingulatus* is common. Sexual dimorphism, with males possessing greatly elongated antennae and abdomen, is noticed in the oriental *Lohita grandis*. *Dindymus sanguineus* is carnivorous. The red bug *Arhaphe carolina* is ant-like with short elytra. *Iphita limbata* and *I. coimbatorensis* (Fig. 57.8) occur in abundance in Kerala on *Hydnocarpus* and *Plumaria*.

▲ **Fig. 57.8** *Iphita coimbatorensis in copula (courtesy: T.I. Jacob)*

1. THE RED COTTON BUG *Dysdercus cingulatus*

In India the bug infests cotton in all cotton growing regions. Adults and nymphs suck the sap from tender parts of the plants and bolls. The plants lose their vigour and bolls open badly with stained lint. They also suck the sap from seeds and make them unfit for sowing or for oil extraction. Further, at the seat a bacterium *Nematospora gossypii* infects the bug affected bolls and spoils the lint. In Tamil Nadu an allied species *Dysdercus olivaceus* is also known to attack cotton.

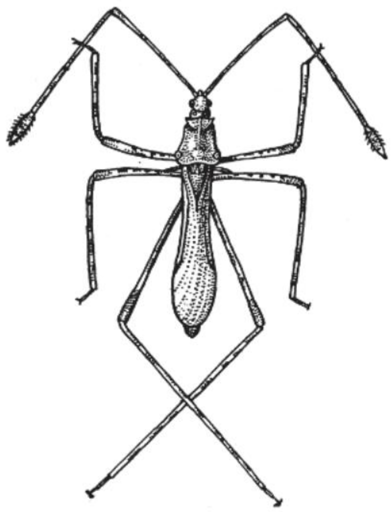
The bug is medium sized with blackish marking on the wings and white bands on the abdomen. The female lays bright yellow spherical eggs in a loose irregular mass in the soil. Incubation period of the egg is about seven days. There are five nymphal instars, the nymphal period being 49 to 89 days.

It attacks cotton, *Abelmoschus esculentus, Zea mays, Pennisetum typhoideum, Hibiscus cannabinus, Solanum verbacifolium,* etc.

The reduviid *Harpactor costalis* is predaceous on the bugs.

Family Berytidae (Neididae)

A small group of bugs with mosquito-like appearance, bearing long legs and slender wings. Femora are apically dilated. *Gampsochoris delhiensis* (Fig. 57.9) lives on the growing tips of bottle gourd plant.



▲ **Fig. 57.9** *Gampsochoris delhiensis (Menon and Ghai) Proc. R. ent. Soc. Lond., B.*(28, 1959)

Superfamily COREOIDEA

This comprises of the families Coreidae, Alydidae, Rhopalidae, Stenocephalidae and Hyocephalidae, of which the first two families are important.

Family Alydidae

Elongate insects with head as broad as pronotum. Fourth antennal segment curved and longer than the third. The important genera are *Alydus, Coriscus, Leptocorisa* and *Protenor*. *Leptocorisa acuta* is a well known pest of rice. These bugs produce penetrating nauseous odour. The odour components comprise of *but-2-enal,oct-2-enal, non-2-enal* and *dec-2-enal,* of which the last one is found in dominant condition.

1. THE RICE BUG *Leptocorisa acuta*

Distribution: It is found in Bhutan, Myanmar, New Caledonia, Sri Lanka, China, Hong Kong, India, West Iran, Indonesia, New Hebrides, Northern territory of Australia, Malaysia, New Guinea, Papua, Pakistan, Philippines, Samoa, Sarawak, Solomon Islands, Taiwan, Tonga, Thailand, Queensland and Vietnam.

Damage: The insect generally appears on rice just before flowering stage and continues until the panicles ripen. The nymphs and adults suck sap from the peduncle, tender stems and milky grains. They suck milky sap from the developing grains of rice by inserting the proboscis at the vulnerable point, viz. the place at which the glumes meet, and due to exudation at the site of feeding, whitish spot appears frequently. As the grain develops it is marked by a diffused yellowish-brown spot. In a panicle the attack will be noticed on individual grains. It has been reported to have caused as much as 49 per cent damage in West Bengal. Its presence in the field is made out by its strong smell.

Life history: The female lays on an average 100 eggs, maximum being about 350, in single or double rows of 10 to 20 per cluster, close to the midrib on the upper surface of leaves. The egg is boat-shaped, dark reddish brown and measures 2 mm long. Incubation period is seven days. The pale yellowish green nymphs possess odoriferous glands on the fifth abdominal segment. There are five nymphal instars, the nymphal period being 15 to 21 days. The adult bug is olive brown and ventrally green. The legs are ochraceous brown. It measures about 15.5 to 17 mm long. The total life-cycle occupies about a month. Adult males live for 48 days and females 60 days. Maturity in both sexes is attained in 8 to 29 days. After the harvest of rice the insect overwinters in millets and wild grasses.

Host plants: *Oryza sativa, Panicum crusgalli, P. colonum, P. flavidum, P. miliare, Sorghum vulgare, Digitaria consanguinalis, Eleusine coracana, Setaria italica, S. glauca, Cyperus rotundus, C. polystachya, Paspalum dilatatum, Pennisetum typhoideum and Saccharum officinarum.*

Natural enemies: The beetle *Cicindela sexpunctata* and the bugs *Asopus malabaricus*, *Euagorus sordidatus*, *Rhinocoris fuscipes* and *Irantha* sp. are predaceous on the bug. The scelionid, *Hadronotus flavipes* is parasitic on the eggs.

Control: Spraying carbaryl 0.05% or malathion 0.05% or dusting quinalphos 1.5% dust controls the pest.

Family Coreidae

These are more or less oval rather then elongate in shape. The head is much narrower than pronotum. They are mostly brownish and phytophagous emanating a pungent scent. In North America *Anas tristis* is a serious pest on cucurbitaceous plants. In India the coreids *Paradasynus* on cashew, *Anoplocnemis phasiana* on brinjal, cowpea, etc., *Clavigralla horrerns, C. gibbosa, Riptortus pedestris* and *R. linearis* on pulses, and *Dasynus antennatus* on oranges are some important pests.

1. THE CASHEW COREID *Paradasynus* sp.

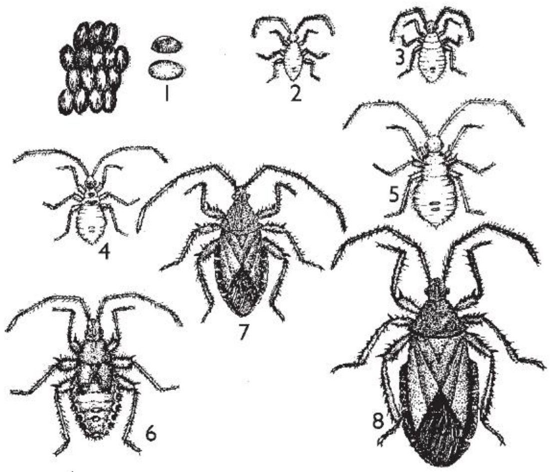
This coreid bug occurs on cashew during March-June in Thiruvananthapuram in Kerala State causing shrivelling and drying up of the tender cashew nuts.

Life history: The adults attain maturity in 10 to 14 days and mate repeatedly. A pair may remain in copulation for an extended period of more than a day. Pre-oviposition period is four days. The female bug lays the boat-shaped yellowish eggs on leaf surface in groups of up to 52 in five or six regular rows. The egg measures 2×1 mm. Incubation period of the egg ranges from 8 to 11 days. The insect passes through five nymphal instars, the successive nymphal instars occupying respectively three to six, three to eight, four to six, three to six and eight to ten days. In the nymphs the antenna is four-segmented with the terminal segment largest and the preterminal segment flat and expanded. The greyish brown adult bug is stout with long legs and without flat expanded preterminal antennal segment.

The eggs are heavily parasitised by *Hadrophanurus* sp. (Scelionidae) and *Anastatus* sp. (Eupelmidae).

2. THE MANGO COREID *Acanthocoris scabrator*

It is a pest of mango in Kerala. It breeds on *Ipomoea carnea*. Female lays 50–60 eggs after seven to nine days of emergence. The incubation period is seven to eight days. There are five nymphal instars, the total period of nymphal development being 50 days. Adults live for three to four months. The adults cause damage to unripe mango fruits by sucking the juice and the attacked fruits eventually rot and drop.



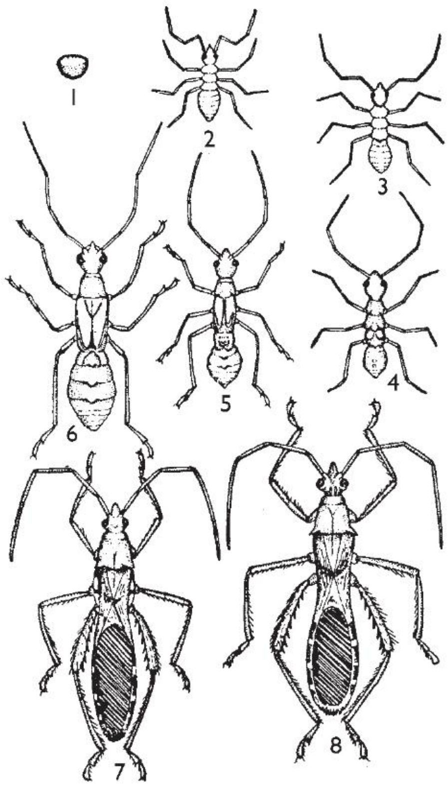
▲ **Fig. 57.10** *1 to 8. Life stages of Acanthocoris scabrator Fabr. 1. Egg (a) Side view, (b) Dorsal view, 2. 1st instar nymph, 3. 2nd instar nymph, 4. 3rd instar nymph, 5. 4th instar nymph, 6. 5th instar nymph, 7. Adult male, 8. Adult female. (After George Koshy, A. Visalakshi and M. R. G. K. Nair,Entomon, 1977)*

3. THE POD BUG *Clavigralla gibbosa*

It is a pest of pulses, particularly of pigeon pea. The eggs are laid on pods in groups of 10-18 and a female lays 79-108 eggs. The egg is yellowish brown, flat, with a slight depression in the center. The incubation period is 10-18 days and there are five nymphal instars. The total nymphal period varies from 22 to 42 days. Adults live for 13 to 30 days.

4. THE COWPEA COREID *Riptortus pedestris*

It is a pest of cowpea, pigeon pea, soybean, moong, lab-lab, *Tephrosia candida, Luffa acutangula,* etc. The adults mate two to three days after emergence and lay eggs 12 to 13 days thence. A female lays about 115 eggs in about 30 days and the egg and nymphal periods being respectively four and 16 days. The adult can live up to 47 days. The nymphs and adults damage the pods by sucking juice out of the fully formed seeds, which as a result shrivel up and become discoloured. Tender pods when attacked, fail to develop fully.



▲ **Fig. 57.11** *1 to 8 : Life stages of Riptortus pedestris 1. Egg, 2. 1st instar nymph, 3. 2nd instar nymph, 4. 3rd instar nymph, 5. 4th instar nymph, 6. 5th instar nymph, 7. Adult male, 8. Adult female. (After A. Visalakshi, Abraham Jacob and M. R. G. K. Nair, Entomon, 1976)*

Superfamily ARADOIDEA

This includes the following families.

Family Aradidae (flat bugs, fungus bugs)

These insects are broad flattened bugs living among fungi, beneath loose bark or in crevices of dead or decaying wood. e.g. *Aradus* sp.

Family Termatophylidae (Termitaphididae) (Termatophilid bugs)

These bugs which look like woodlice are broadly oval, apterous, flat, blind bugs and inhabit termite galleries.

Superfamily SALDOIDEA

Family Saldidae (shore bugs)

These small, oval, flattened bugs are seen along the shores of streams, ponds or the ocean, inhabiting mud, moss or salt-marsh plants. These insects are predaceous in habit.

Family Thaumastotheriidae (Thaumastocoridae) (royal palm bugs)

These small insects with broad head are represented in North America and Australia. In America these infest the royal palm.

Superfamily PENTATOMOIDEA

Usually possess five-segmented antennae. Tarsi two or three segmented. This includes the following families viz. Acanthosomatidae, Cydnidae, Pentatomidae, Plataspididae, Podopidae and Scutelleridae.

Family Cydnidae (burrower bugs)

These are oval, dark coloured bugs characterised by provision of expanded and spiny tibiae adapted for burrowing beneath stones, in sand or in the soil. Some are known to live in ant nests. In Coimbatore sometimes the nymphs and adults of the reddish brown flattish bug *Stibaropus tabulatus* infests the roots and rootlets of tobacco plants in the soil. The attacked plants become stunted and gradually die. *S. molginus* infests roots of palm in South India. *S. minor* infests sorghum and *Pennisetum typhoideum* in Uttar Pradesh. In Rajasthan *Stibaropus* sp. infests roots of *Sorghum vulgare* and *Pennisetum purpureum.*

Other Indian species are *Chilocoris nitidus*, *Chilocoristoides assumthi*, C. *solenopsides*, *Cydnus ater, Geotomus acrostictus, Lactistes* sp. and *Macroscytus* sp.

Family Plataspididae (Negro bugs)

These bugs are small, broadly oval and strongly convex with the scutellum covering most part of the abdomen and wings. These insects are phytophagous. In India *Coptosoma cribraria* on pulses, lab-lab, *Sesbania grandiflora*, etc., *Coptosoma ostensum* on *Butea*, *Coptosoma nazirae* on cluster beans, mango, etc., and *Brachyplatys vauhlii* on *Sesbania grandiflora* are common.

Family Scutelleridae (shield-backed bugs)

The scutellum is very large and extends to the apex of the abdomen, exposing the wings at its edge. The insect is generally brownish, 8-10 mm long and phytophagous. The Indian species are: *Cantao ocellatus* the female of which broods over her eggs in nature and exhibits maternal solicitude. *Chrysocoris stollii* is a pest of litchi in North India. *Hotea curculionoides* and *H. nigrorufa* occur on sandal trees.

1. THE LITCHI BUG *Chrysocoris stollii*

The insect is found in the region from India to South China, Myanmar, Nicobars, Formosa and North China. In North Bihar (India) it inflicts damage to litchi and logan.

The insect is prevalent throughout the year excepting the months December and January. It feeds on *Croton sparsiflorus, Clerodendron unfortunatum* and *Litchi chinensis.*

Mating takes place end to end and the pair remains in copulation for a long period. The pre-oviposition period is a day. A female lays up to 22 eggs. Egg is oval and creamy white. Incubation period of the egg is five to seven days. The nymph undergoes five moults, the durations of successive nymphal instars being 2.5 to 3.5, 3.5 to 6, 3 to 6, 5 to 6 and 5 to 7 days. The adult bug is green with six spots on the thorax in two rows and seven spots on the scutellum which covers the abdomen completely.

Family Podopidae (terrestrial turtle bugs)

Smaller insects measuring about 3.5 to 10 mm long, generally brownish with a long scutellum and pronotum bearing a prominent tooth or lobe in front of the humeral angle. They are rare in occurrence.

1. THE JAPANESE BLACK BUG *Scotinophara lurida*

The insect is distributed in India, Pakistan, Sri Lanka, Thailand, Vietnam, Malaysia, Japan, China, Taiwan, Okinawa and Celebes.

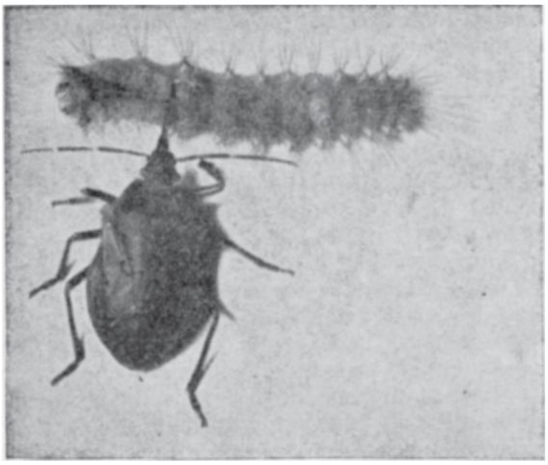
Severe infestation of the bug on rice adversely affects the tillers which may even die in due course. The damage is due to the toxin injected by the bug at the site of feeding. Initially it causes yellowing of plants. Crop more than two months old may escape damage. However, if infestation is severe at milky stage, grains do not mature properly resulting in lower yield.

The brownish black bug is 10 mm long with a prominent scutellum and pronotum having a spine on either side. The female lays the eggs in two longitudinal rows, each row having about seven eggs, on the lower leaves of rice. On an average 190 eggs are laid by a female, the maximum being 600 eggs. The incubation period is six days. The nymphal period is about 42 days. Adults have a longevity up to ten months. It is said to aestivate in the adult or late nymphal stage in cracks in bunds.

It infests *Oryza* sativa, *O. minuta. Panicum crusgalli, Setaria italica,* wheat, barley, sugarcane and *Zea mays.*

Family Pentatomidae (stink bugs)

These are moderate to large sized, often brightly coloured insects with five-segmented antenna and a triangular scutellum. They are broad, shield-like in shape and produce a disagreeable odour. The bases of antennae are concealed by the lateral margins of the head. The stink bugs belonging to the subfamily Pentatominae are mostly phytophagous. Those belonging to Acanthosominae and Asopinae are mostly predaceous on other insects and some others feed on both plant sap and insects (Fig. 57.12). The eggs of stink bugs are barrel shaped with the upper end ornamented with spines. The eggs are usually laid side by side in groups.



▲ **Fig. 57.12** *Pentatomid bug predaceous on gypsy moth larva (courtesy: V.P. Rao)*

Predaceous Pentatomid Bugs

Eocanthecona furcellata and *Andrallus spinidens* are the two common predaceous bugs noticed in South India.

1. Eocanthecona furcellata

The bug is found distributed in the Oriental and Nearctic regions.

The bug lays 8 to 60 eggs in two rows on the food plant. A female lays a maximum of 180 eggs. The incubation period ranges from five to seven days. There are five nymphal instars. The development from egg to adult occupies 18 to 21 days. Longevity of the adults is 15 to 20 days. Cannibalistic tendency is noticed in this species.

The early instar nymphs feed on host plant and later become predaceous on other insects. Both nymphs and adults approach insect caterpillars from behind, place the rostrum in between the two anal prolegs and thrust the stylets into the body of the larvae and suck the body fluid. The larvae thus get killed hang head downwards.

The bug is predaceous on larvae of *Amsacta albistriga, Spodoptera exigua, Spodoptera litura, Athalia lugens proxima, Thosea cervina, Utetheisa pulchella, Hyblaea puera* , *Antheraea* sp., *Semiothisa pervolgata, Eurema hecabe* , *Catopsilia pyranthe, Helicoverpa armigera* and *Thiacidas postica.*

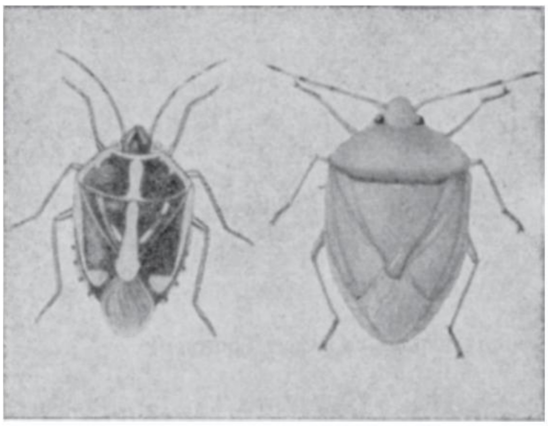
2. Andrallus spinidens

This is a widely distributed species found in the Malay Archipelago, Fiji, Tahiti, East Africa, Mexico, Pakistan and India. Life history and habits are similar to E. *furcellata.* Cannibalistic tendency is noticed in this species.

Both adults and late instar nymphs are predaceous on larvae of *Spodoptera litura, Semiothisa pervolgata, Catopsilia pyranthe, Eurema hecabe, Anticarsia irrorata, Helicoverpa armigera* and *Pelopidas mathias.*

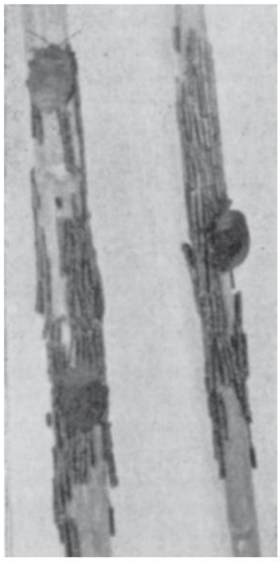
Phytophagous Pentatomid Bugs

Though a large number of species infest a variety of crop plants they are in general of minor importance. The following are some of the common pentatomid bugs that infest crops in India. *Tetroda histeroides* and *Menida histrio* on rice, *Dolycoris indicus, Nezara viridula, Piezodorus rubrofasciatus* and *Menida histrio* on millets, *Bagrada cruciferarum* (Fig. 57.13) on cruciferous vegetable crops, *Aspongopus janus* and *A. brunneus* on cucurbitaceous crops, *Antestiopsis cruciata* on



▲ **Fig. 57.13** *Left—Bagrada cruciferarum Right—Nezara viridula (Fletcher)* jasmine and coffee, *Cyclopelta siccifolia* (Fig. 57.14) on *Pongamia glabra* and *Sesbania speciosa*, etc.

1. THE ARECANUT BUG *Halyomorpha marmoreal*: It is associated with tender nut drop in arecanut in Karnataka to the extent of 10–20% during April, which becomes severe during monsoon. It lays on an average four egg clusters in a triangular formation on the rachis, each egg cluster having 28 eggs. The egg is spherical, cream coloured and measures 0.9 to 1.0 mm long. Incubation period is four to six days and nymphal period occupies about 36 days. Both fifth instar nymphs and adults feed on the tender nuts of arecanut. The bugs pierce the fibrous pericarp and soft kernel and suck the sap continuously for two to four hours. The nuts get detached from the rachis and drop.



▲ **Fig. 57.14** *Cyclopelta siccifolia (S.K. David and S. Venugopal)*

Series 2. AMPHIBICORISAE

Aquatic bugs living on water surface; includes only one superfamily, the Gerroidea. This includes the families Gerridae, Hebridae, Hydrometridae, Mesoveliidae and Veliidae.

Superfamily GERROIDEA

Family Gerridae (pond-skaters or water striders)

These are predaceous bugs, which live on the surface of water, running or skating over the water film. Head is elongate and slender with a four-segmented rostrum. The forelegs are short and are used in capturing the prey whereas the long middle and hindlegs are used in locomotion. The tarsi are two-segmented and clothed with fine hairs which do not get wet and thus enable the insect to move about on the water surface. A scent gland is present on the metathorax. Winged and wingless forms are noticed in many species. They inhabit fresh water streams excepting those belonging to the genus *Halobates*, which lives on the surface of ocean, often many kilometers away from land. The water strider *Gerris tristan*, commonly found in paddy fields, is predaceous on *Nilaparvata lugens*.

Family Mesoveliidae (water treaders)

The water treaders are small insects with a large head, eyes, and long delicate legs. Winged and apterous forms are met with. They are capable of running on the surface of water. They are found among the leaves of aquatic plants and feed on small aquatic organisms. e.g. *Mesovelia.*

Family Hebridae (velvet water bugs)

The bugs are very small, stout and are semiaquatic. The velvety hairs found on its body prevents it from becoming wet. It is capable of running or walking on the surface of water.

Family Hydrometridae (water measurers, marsh treaders)

These bugs are slender, small, greyish bugs resembling tiny walking sticks. The long head bears the eyes which conspicuously bulge out laterally. They are seen among vegetation on shallow waters and feed on minute organisms. These bugs move about slowly on the surface of stagnant water. e.g. *Hydrometra.*

Section 3. HYDROCORISAE

Mainly aquatic sometimes semi-aquatic; antennae shorter than head. Three superfamilies viz. Corixoidea, Notonectoidea and Ochteroidea are recognised.

Superfamily CORIXOIDEA

Family Corixidae (water boatmen)

Aquatic bugs with dorsally flattened body which inhabit common fresh water ponds and lakes, and occasionally streams. A few occur along the seashore in brackish pools. The head is not inserted into the prothorax. The one or two-segmented rostrum is concealed. Antennae are three- or four-segmented. The forelegs are very short with spatulate tarsi which help in scooping up its food materials while feeding. Claws are wanting in fore- and hind legs and tarsi are two-segmented. Stridulatory organs are present.

Most species are microphagous and feed on algae and other minute aquatic organisms. A few are predaceous on midge larvae and other small aquatic animals. These bugs do not bite man. They remain at the bottom of water clinging to various objects with their middle legs. They frequently come to the surface of water propelled by their hind legs and carry a bubble of air under water either on the surface of the body or in the space or reservoir between the somewhat concave dorsal surface of the abdomen and the undersurface of the wings.

The eggs are usually attached to stems and leaves of aquatic plants. The eggs in some may be laid closely grouped together in large numbers. The eggs of *Arctocorixa abdominalis* and *A. mercenaria* are used as food by the Mexican Indians. The adults are also used as food in Mexico and Egypt, and many aquatic animals also feed on them.

Superfamily NOTONECTOIDEA

Family Notonectidae (Back-swimmers)

These light coloured bugs swim upside down and hence the name "back-swimmers." The body is more convex dorsally. The head is inserted into prothorax and possesses four-segmented antennae and a three- or four-segmented rostrum. Tarsi are two-segmented. The foretarsi are not flattened and the posterior tarsi are clawless.

They float on the surface of water with the head down and body at an angle, and using the long outstretched oar-like hindlegs swim rapidly. They are capable of diving carrying a bubble of air beneath the wings and also leaping into the air and taking to flight.

These bugs are predaceous on fishes, tadpoles, etc. and inflict painful puncture to man when handled. The eggs may be either inserted into plant tissue or attached to aquatic plants. *Notonecta* is a widely distributed form of back-swimmers. In India *Anisops bouvieri* is common in fish ponds.

Anisops bouvieri: It is a very common insect predator found in fish ponds in India. It feeds voraciously on fishes, larvae and nymphs of other aquatic insects like mosquito and chironomid larvae and mayfly nymphs and different types of planktonic crustaceans. During period of starvation it develops cannibalistic tendencies. The prey is captured by its raptorial fore and middle legs which are well armed with spines and claws.

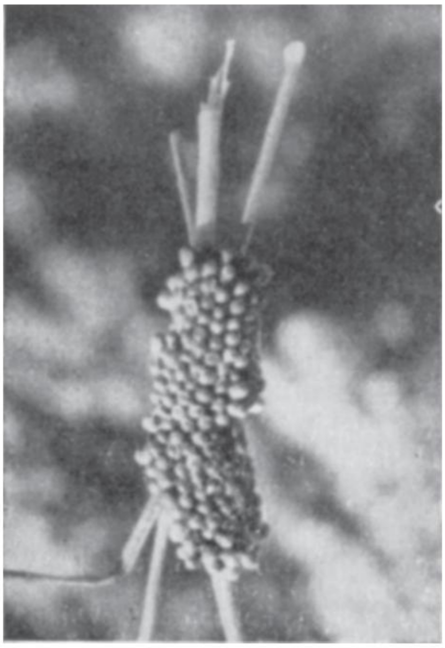
The female inserts the eggs into the leaves and stems of aquatic plants like *Ipomoea aquatica*, *Chara* sp., *Vallisneria spiralis*, *Hydrilla verticillata*, *Hydrophila polysperua* and *Spirodela polyrhiza*. A female lays in about 7 weeks about 617 eggs. The incubation period is about 7 to 9 days. The total developmental period from egg to adult takes about 33 days.

Family Nepidae (water scorpions)

These are predaceous aquatic bugs. Antennae are three-segmented. The forelegs are raptorial whereas the hindlegs are adapted for walking. Tarsi are one-segmented and in forelegs claws are absent. A caudal breathing tube formed by the cerci is very characteristic of the water scorpions. It is protruded out of the surface of water when the insect is submerged and air is conducted to the spiracles at the base of the tube. A painful bite is inflicted to man when handled. The most common water scorpions belong to the genera *Ranatra* and *Laccotrephes*.

Family Belostomatidae (giant water bugs)

The largest members of the Heteroptera are found in this family. The bug *Lethocerus grandis*, exceeds 190 mm in length. They are brownish oval and somewhat flattened and possess four-segmented antennae. The forelegs are prehensile. The middle and hindlegs have tibiae flattened with fringes of hairs and adapted for swimming. Two retractile apical abdominal appendages are present. Air is stored beneath the wings in the reservoir formed by the some- what concave dorsum of the abdomen.



▲ **Fig. 57.15** *Egg cluster of Belostoma attached to an aquatic plant (After T. K. R. Rao)*

These bugs occur in ponds and lakes and are predaceous on other insects, fishes, tadpoles, snails, etc. They are phototropic and are attracted to lights frequently. They inflict a painful bite to man if handled carelessly. In *Sphaerodema* the eggs are cemented to the back of the male, which carries them until they hatch. In others like *Belostoma* the eggs are either attached to the aquatic plants (Fig. 57.15) or laid at the bottom of ponds.

Superfamily OCHTEROIDEA

These are semi-aquatic insects and are represented by two families viz. Ochteridae and Gelastocoridae.

SUBORDER HOMOPTERA

This is a diverse group of bugs with wings sloping over the body in winged forms. Rostrum extends to the base of the first coxae. Tarsi 1–3 jointed. Three series of Homoptera are recognised : In Auchenorrhyncha and Sternorrhyncha the origin of the rostrum is more cephalic in the former, and more thoracic in the latter. The Auchenorrhyncha is more a classification for convenience to include forms which are different from Sternorrhyncha. Sternorrhyncha include aphids, aleyrodids, psyllids and coccids, all other Homoptera are included in Auchenorrhyncha. The series Coleorrhyncha are characterised by three-segmented short antennae without terminal arista, concealed beneath the head. This series is not represented from India.

SERIES AUCHENORRHYNCHA

Two primary groups viz. Cicadomorpha and Fulgoromorpha are recognised. Cicadomorpha comprises of three superfamilies viz. Cicadoidea, Cicadelloidea and Cercopoidea

GROUP CICADOMORPHA

Superfamily CICADELLOIDEA

Family Membracidae (tree-hoppers or cow-bugs)

Characterised by two ocelli. Antennae lie in a depression beneath and in front of the eyes. They are generally smaller measuring up to 10–12 cm long. Stridulatory organs absent.

They usually move about by jumping. Membracids are provided with pronotum extending backward over abdomen and ornamented with various spines, horns, keels, bell-like knobs, etc. of various shapes. Wings are largely concealed by pronotum.

They suck the sap from trees, shrubs and cultivated crops and most species are host specific. Principal damage is caused by egg-laying. Ants are found associated with the membracids. Ants stroke the bugs by their antennae which makes them to exude the honeydew for the ants. Reduction or modification of external genitalia due to parasitisation, i.e. "Castration parasitaire," has been observed in certain genera such as *Telamona, Thelia*, etc.

Over 2000 species are known. The common treehoppers of some economic importance are as follows:

1. THE TREEHOPPER Tricentrus bicolor

This is widely distributed, in India and has been reported to be a common pest on *Medicago sativa* (lucerne) and *Trifolium alexandrinum* (berseem) and occasionally on *Cajanus cajan*, *Sorghum*, sugarcane, wheat, pea, rose, wild grasses, *Zizyphus, Acacia*, etc. in Udaipur.

Life history: The males are generally darker in colour and more active than the females. They remain in clusters at the axils of branches or near the midrib of leaves on adaxial sides. The common black ant *Camponotus compressus* attends on the nymphs and adults for their honeydew excretion. The insect is prevalent throughout the year but abundant during September-October.

They generally mate during warmer seasons. Grasping the female in between the forelegs the male mounts and continues pairing in head-to-head position for several hours. Soon after copulation the female selects the lower surface of the tender branches not exposed to the sun directly and oviposits. Sometimes eggs may be laid along the midrib of the leaf, petiole, buds or even leaf lamina. The female cuts a longitudinal slit on the bark and inserts the eggs, which may be laid singly or in groups, the first few being embedded completely, and the subsequent ones appear only partly within. If laid singly they lie parallel to the twig and if in groups of five or six they are arranged obliquely in two rows, each pair arranged as a V. In the case of *Oxyrhachis tarandus* and *Leptocentrus obliquus* the eggs are superficially glued to the bark in a peculiar pattern in two rows.

Egg measures 0.13 mm long and 0.15 mm broad. When freshly laid it is translucent and pale green but changes to dark brown in due course. Incubation period varies from 8 to 13 days.

The insect undergoes five moults within 33 to 55 days. The newly hatched nymph is sedentary, more or less soft bodied and shining greenish brown in colour. The fifth instar nymph is brown with lateral dark bands.

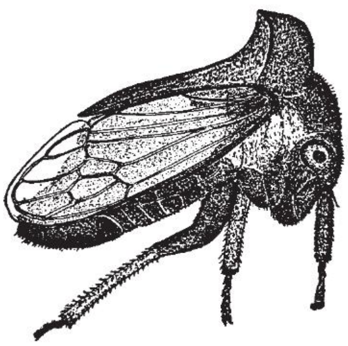
Adult is black and setose with a prominent and sub-triangular pronotum overlapping the entire prothorax. Two hollow horn-like recurved suprahumeral arms give it a dagger-shaped appearance in lateral view. The apex is prolonged posteriorly into a robust posterior spine.

There is significant correlation of population with temperature but no correlation with humidity either individually or in combination with temperature.

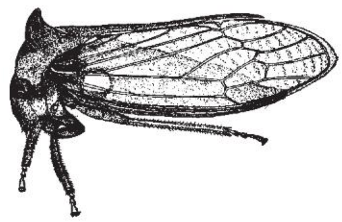
Host plants: Wheat, maize, barley, rice sorghum, *Pennisetum typhoideum*, *P. purpureum*, lucerne, berseem, *Cyperus rotundus*, *Cynodon dactylon*, pea, *Cicer arietinum, Phaseolus aureus, P. mungo, Cajanus cajan,* sugarcane, cotton, potato, groundnut, gingelly (*Sesamum indicum*), cabbage, cauliflower, chillies (*Capsicum annuum*), *Solanum melongena*, tomato, *Abelmoschus esculentus*, *Mangifera indica*, *Psidium guajava. Citrus aurantifolia*, C. *reticulata, Zizyphus mauritiana, Polyalthia longifolia, Rosa chinensis, Grevillea robusta* and *Hibiscus rosasinensis.*

Control: Lindane, phosphamidon and malathion are effective.

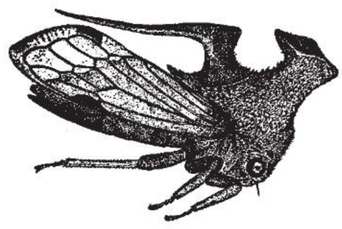
Among other membracids *Tricentrus congestus* (Fig. 57.16), *Otinotus mimicus* (Fig. 57.17), *Anchon pilosum* (Fig. 57.18), *Leptocentrus* sp., *Oxyrhachis* sp., etc. are of importance. *A. pilosum* is a pest specifically found on lab-lab.



▲ **Fig. 57.16** *Tricentrus congestus (Courtesy: Ananthasubramanian)*



▲ **Fig. 57.17** *Otinotus mimicus (ibid)*



▲ **Fig. 57.18** *Anchon pilosum (ibid)*

Family Cicadellidae [Jassidae] (leafhoppers)

This family includes a large number of variously sized insects possessing different forms and colour. Many are strikingly coloured. They rarely exceeds 13 mm in length. They are generally small in size with elongate body tapering posteriorly. There are two ocelli. Antennae possess sensoria, apical part being long and setaceous. Hindtibiae with double rows of small spines extend all over its length. Movable tibial spur absent. With its ovipositor the female lacerates the plant tissue and inserts the longitudinal eggs inside the stem, leaf sheath or leaf in longitudinal rows. There are six instars, the wing rudiments being prominent from the third instar onwards. They have the habit of running side ways.

Leafhoppers feed on almost all kinds of vegetation–trees, shrubs, plants, grasses and crops, and suck the sap from the leaves, flower stalks and tender stems. Most species are host specific. Some pass through one generation in a year and others two or three generations in a season.

A number of species are economically very important as they inflict damage to crops in various ways by sucking the cell sap and injecting toxins into the plant tissue. By sucking sap from leaves some species cause minute white or yellowish spots or yellowing of leaves. In some species feeding interferes with normal physiology of the plants and cause drying or "hopper burn" symptoms. Oviposition injury may be noticed in a few cases. Some are known to be vectors of virus diseases. Curling of leaves and stunting of plants are caused by some. Honeydew excretion of some species results in formation of sooty mould on leaf surface.

Some of the important plant diseases transmitted by leafhoppers in the U.S.A. are potato yellow dwarf by *Aceratagallia sanguinolenta*, corn stunt by *Baldulus maidis*, aster yellows by *Macrosteles divisus*, phloem necrosis in elm by *Scaphoideus luteolus* and curly top in sugar beet by *Circulifer tenellus*. The green rice leafhoppers *Nephotettix nigropictus* and *N. virescens* are vectors of dwarf and yellow dwarf viruses in rice. Sesamum disease is transmitted in India by the cicadellid, *Orosius albicinctus*. *Cestius phycitis* is a well known vector of the "little-leaf" disease of *Solanum melongena*.

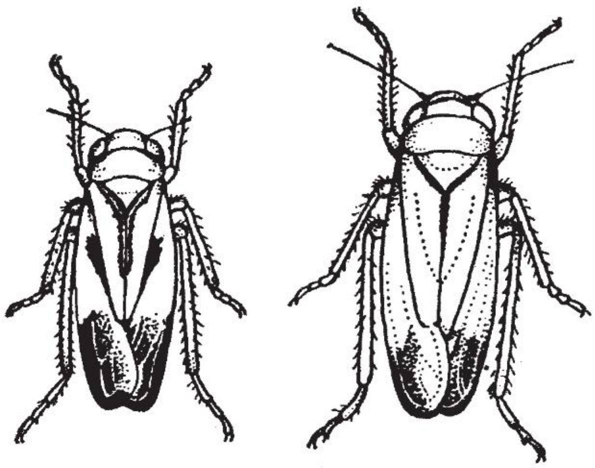
The following are some of the species found in India.

1. THE GREEN RICE LEAFHOPPER *Nephotettix nigropictus* (Fig. 57.19)

This is a small, active wedge-shaped leafhopper measuring about 5 mm long and possesses two black spots in the males which extends up to the black distal portion of the forewings. Males have a black tinge along the anterior margin of pronotum. Crown of the head has a black submarginal band which may be incomplete sometimes in female. Female is generally entirely green without any black tinge on pronotum.

Distribution: It has a wide distribution in all rice growing countries and is known from southern Japan to Oriental region, south to Australia and westward of South Africa.

Damage: In cases of very severe infestation both nymphs and adults suck the sap from leaf sheaths and blades and cause browning of leaves or “hopper burn.” In general its attack causes uniform yellowing of leaf from tip to the middle half of leaf. However, serious damage is inflicted when it transmits the virus diseases such as rice dwarf, rice yellow dwarf, rice transitory yellowing and rice Tungro. Plants infected with dwarf or stunt virus show symptoms of veins of leaves having a series of white dots on the midribs developing into parallel yellowish streaks. Leaves become chlorotic. The honeydew excreted by the leaf hoppers favour multiplication of sooty mould caused by *Capnodium* sp.



▲ **Fig. 57.19** *Nephotettix nigropictus female and male*

Life history: The adult female with its ovipositor makes a vertical incision in the leaf sheath and the yellowish eggs are laid in a row across the incision under the epidermis. The egg is about 1 mm long and 0.3 mm broad. A female lays up to 53 eggs. In a single row up to 24 eggs may be laid. The nymphs hatch out from the eggs in six or seven days. They pass through five instars and become adult in about 18days. On an average the life-cycle occupies 23 days. The female lives for about 55 days. Its peak period of occurrence in South India. has been found to be July to September.

Host plants: It is primarily a pest of rice in India but during off-season it thrives on grasses. Alternative host plants noticed elsewhere are *Alopecurus pratensis, Cynodon dactylon, Cyperus* *rotundus, C. esculentus, C. scariosus, Celosia argentea, Eichhornia crassipes, Echinochloa crusgalli, Eragrostis amabalis, Eleusine indica, Kylinga monocephala, Poa annua, Panicum crusgalli, P. ramosum* and *Setaria italica.*

Control: Spray application of phosalone, cartap hydrochloride, monocrotophos, acephate, chlorpyrifos, carbaryl, etc. at 0.5 kg a.i./ha or fipronil or etofenprox at 50 g a.i./ha, or granular insecticides such as phorate 10G, chlorpyrifos 10G, lindane 4% + carbaryl 4% G, cartap hydrochloride 4G at 1 kg a.i./ha or fipronil 0.3% G at 25 kg/ha have been found effective in controlling this pest.

2. *Nephotettix virescens*

This insect is found along with *N. nigropictus* and has identical distribution.

This species can be easily distinguished from the previous species by the absence of the black submarginal band on the crown. In the male the black spots do not extend up to the black distal portion of forewings. Further, the central tegminal marking usually does not touch the cleval suture. On the pronotum black tinge is absent.

This insect also transmits Tungro of rice, rice transitory yellowing and rice yellow dwarf. Biology and control are similar to those of *Nephotettix nigropictus. N. virescens* causes appreciable damage to rice crop than *N. nigropictus.* The egg is parasitised by *Oligosita nephotetticum.*

3. THE WHITE RICE LEAFHOPPER *Tettigella spectra*

Distribution: This larger insect is widely distributed in subtropical and tropical regions and is primarily an Oriental species.

Damage: Nymphs and adults suck the sap and cause yellowing of leaves, which commences from the tip and margin, and then proceeds towards the middle and to the base. Reduction in the height of the tillers in cases of severe infestation is appreciable. The insect is not known to transmit any virus disease in rice.

Life history: This is very common in rice fields. It is greyish-white with the face swollen or rounded. Four black spots are seen on the head. The female makes an incision with its ovipositor on the leaf sheath and inserts the eggs. As many as 17 egg masses are inserted by a female, the number of eggs in each mass varying from 5 to 17. A female lays as many as 164 eggs. Incubation period is six to seven days. There are five nymphal instars occupying a period of about 18 days. The female lives for 30–35 days.

4. THE ZIGZAG STRIPED LEAFHOPPER *Recilia dorsalis*

Distribution: This insect is widely distributed in India, Pakistan, Sri Lanka, Malaya, Vietnam, Philippines, Japan and Korea.

Damage: Tip drying and orange colouration of both margins of leaves are typical symptoms. Older leaves show the symptoms first, followed by the younger leaves. Development of sooty mould also takes place. Seedlings are killed if infestation is heavy. The leafhopper is known to be a vector of rice dwarf and orange leaf disease. Only the female is viruliferous.

Life history: It is a whitish-grey insect and has V shaped zigzag brown line on the forewings. It measures about 5–7 mm in length. The female lays its eggs scattered on the leaf sheaths or on the leaves inside the tissue. Usually it lays one or two eggs at a time and rarely in masses of three or four. A female may lay as many as 90 eggs. Incubation period is six days. There are five nymphal instars passed in about 120 days. The total life cycle from egg to adult occupies about 180 days. Adult female has a longevity of about 55 days.

Control: As for *Nephotettix nigropictus*

5. THE RICE BLUE LEAFHOPPER *Empoascanara maculifrons*

Distribution: Throughout South-East Asia and India.

Damage: It is primarily a pest on rice in the nursery, causing death of seedlings in cases of severe infestation. Formation of characteristic whitish waxy lines on leaf blades in the initial stages of attack and subsequent drying are specific symptoms. They also attack leaf sheaths. It is not known to be a vector of any virus disease in rice.

Life history: This is a very small, blue leafhopper with yellowish vertex having a black patch in the middle and pronotum. The female inserts the eggs in the leaf sheath or in the upper midrib of leaf blade in batches of two, three or four and a female lays as many as 64 eggs. Incubation period is 10-11 days. There are five nymphal instars of about 13-14 days. The life-cycle from egg to adult takes about 23–25 days. Adult female has a longevity of 45–50 days.

Control: As for *Nephotettix nigropictus*

6. THE SESAMUM CICADELLID *Orosius albicinctus*

Distribution: Throughout India.

Damage: This cicadellid is the vector of the sesamum phyllody virus.

Life history: In India its biology has been investigated on *Crotalaria juncea*. Mating occurs during dusk, and lasts for 3-4 minutes. Both the sexes mate several times. Pre-oviposition, oviposition, and post-oviposition periods during winter lasts 73, 13 and 15 days respectively and during summer 2, 27 and 5 days respectively. A female may lay as many as 256 viable eggs. Eggs are inserted singly into midribs or veins, on the undersurface of petioles and stem of young plants. The average fecundity-cum-fertility is 6.5 during December-March and 140 during April-May. The incubation period ranges from six days in June to 96 days in December, the nymphal period being 11 to 107 days in different seasons. Longevity of adult ranges from 19 to 105 days depending on the season. Sex ratio is 1:1. The insect is predominant during summer.

Natural enemies: The coccinellid *Brumoides suturalis* is predaceous on the early instar nymphs. In the green house, adults are infested by the fungi *Aspergillus flavus* and *Cladosporium tenusemium* which are weakly pathogenic.

Control: Dimethoate and carbaryl are effective in controlling the cicadellid.

7. THE BRINJAL CICADELLID *Cestius phycitis*

Distribution: India and Sri Lanka.

Damage: It is a well known vector of the "little-leaf" virus disease in the egg-plant *Solanum melongena.*

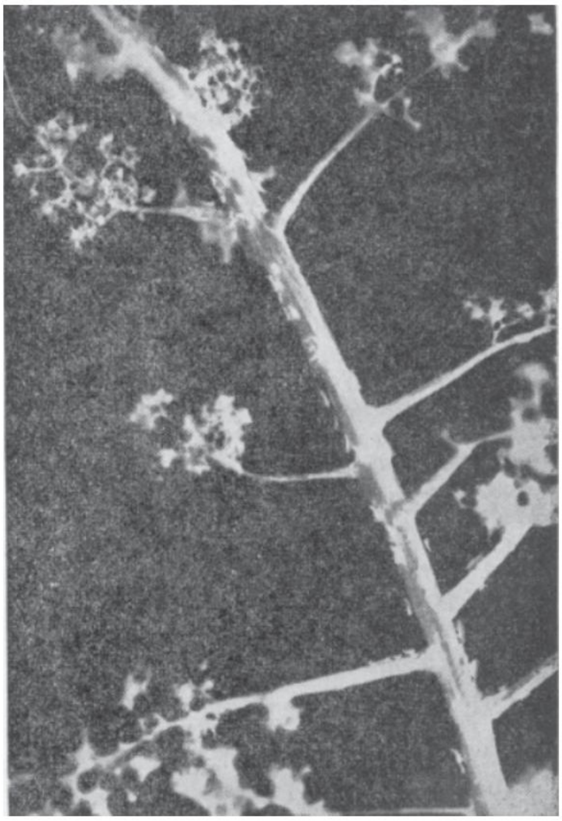
Life history: The planthopper lays its eggs mostly during day time in the midrib, lateral thick veins, petioles and tender stems of young plants. At Ludhiana (India) the incubation period ranges from 8 to 23 days in different months. The insect passes through five nymphal instars in 14 days in September and 69 days in November–January. As many as 337 eggs are laid by a female. The pre-oviposition, oviposition and post-oviposition periods are 4, 20 and 8 days respectively during July-August and 3, 22 and 28 days during October-November. Adult longevity is three to six weeks and maximum of 94 days in winter. Both sexes mate more than once. Sex ratio is 1:1.

Host plant: *Solanum melongena, Gossypium arboreum, Sesamum indicum*, *Daucus carota, Cyamopsis tetragonoloba, Sesbania cannabina, Citrus aurantifolia, C. reticulata, C. sinensis, Medicago sativa, Phaseolus aconitifolius, Raphanus sativus* and *Crotalaria juncea.*

Natural enemies: The coccinellids *Cheilomenes sexmaculatus* and *Brumoides suturalis* are predaceous on the insect. The fungus *Aspergillus flavus* is parasitic on adults.

8. THE MANGOHOPPERS (Figs 57.20 and 57. 21)

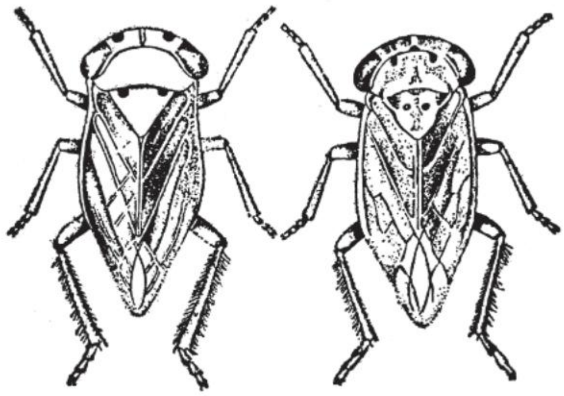
Distribution: Three species of leaf hoppers attack mango inflorescence throughout India.



▲ **Fig. 57.20** *Idioscopus sp. on mango inflorescence*

Damage: The injury is due to: 1. Heavy egg laying on the inflorescence stalk and florets which causes withering and dropping, and 2. Adults as well as nymphs which pierce the tissues of flower panicles and suck the sap causing withering and shedding of flowers. In case of severe attack honeydew excreted by the hoppers cover the inflorescence and leaves giving rise to development of sooty mould which hinders the setting of fruits. Loss due to hopper varies from 25 to 60 per cent. The extent of damage caused may vary in different years as in some years the attack may be severe while in some years it may be slight.

Life history: *Idioscopus niveosparsus* is slightly smaller and has prominent white bar crossing its dusky wings and three spots on the scutellum. *I. clypealis* is the smallest, lighter in colour with two spots on the scutellum and dark spots on the vertex. *Amritodus atkinsoni* is the largest, light brown with two spots on the scutellum. In South India *I. niveosparsus* is the most injurious species. They are found all through the year hiding on the bark or leaves of mango till the trees put forth their blossoms. The insects appear in large numbers during cold weather (November to February) as soon as the flower buds begin to form. Eggs are inserted into the florets and stalk of the inflorescence and the eggs hatch in four to seven days. The nymphal period is 8 to 10 days. The total length of the life-cycle from egg to adult varies from 12 to 17 days. There may be two or three broods during the blossoming period of mango.



▲ **Fig. 57.21** *Idioscopus sp.*

Natural enemies: The natural enemies of the mangohoppers includes *Pyrilloxenos compactus* (Strepsiptera), *Epipyrops fuliginosa* (Epipyropidae), *Pipunculus annulifemur* (Pipunculidae) and the entomogenous fungi *Isaria stellata* and *Hirsutella versicolor*.

Control: Three applications of carbaryl 0.1% or etofenprox 0.03% or phosalone 0.05% at fortnightly interval affords control.

9. THE CASTOR LEAFHOPPER *Empoasca flavescens*

Distribution: Throughout India.

Damage: Plants with heavy populations of nymphs show characteristic symptoms of hop-per burn. The initial symptom is formation of yellow patches in the margins of leaves which is followed by distortion of veins and leaf curling. This subsequently changes to brown. The leaf becomes brittle and dries. In cases of severe attack the plant loses its vigour and results in poor formation of capsules. Different varieties possess different degrees of resistance and susceptibility to leafhopper attack.

Life history: The leafhopper is green or greenish yellow. The female inserts its eggs inside the veins of leaves and may lay from 15 to 37 eggs; the oviposition period is five to seven days. The incubation period is seven to eight days and there are five nymphal instars passed in 9.5 days. The entire development from egg to adult occupies about 17.5 days. The average longevity of male and female will be 9 and 17 days respectively. The insect multiplies in large numbers during November-January and the minimum population level is noticed during the hot weather and South-West monsoon periods.

Host plants: It is primarily a pest of castor *(Ricinus communis)*. Tea, cotton, lady's finger, brinjal and potato are also hosts of the insect.

Control: As for *Nephotettix nigropictus.*

10. THE COTTON LEAFHOPPER *Empoasca devastans*

Distribution: This is one of the important sucking pests of cotton in all cotton growing regions in India.

Damage: With the introduction of American cottons in the Punjab about 80 years back the insect came into prominence in India. Nymphs and adults remain in large numbers and suck the sap from the undersurface of leaves and cause yellowing, curling, bronzing and even drying up of leaves. The crop becomes stunted and often in highly susceptible varieties it causes complete mortality of plants if left unprotected. The susceptible and tolerant varieties react differently to the toxic saliva and based on the symptoms of "hopper burn" injury they are graded for leafhopper resistance.

Life history: The leafhoppers mate early in the morning or late in the evening. The female inserts its eggs inside the leaf veins in the parenchymatous tissue. On an average a leafhopper lays about 15 eggs but may lay as many as 29 eggs. The hatching period varies from 4 to 11 days. There are five nymphal instars and the nymphal period occupies about seven days in autumn and 21 days in winter. Longevity of mated adults is about five weeks in summer and seven weeks in winter, and unmated adults live three months or longer. The winter brood individuals are reddish while summer broods are greenish yellow. In Punjab there are 11 generations of the insect with considerable overlapping. Each brood occupies from 15 to 46 days depending on the environmental conditions.

Host plants: Castor, hollyhock (*Althaea rosea*), brinjal, potato, *Hibiscus cannabinus, Abelmoschus esculentus*, *Hibiscus vitifolius*, *Helianthus annuus* and cucurbits.

Natural enemies: *Chrysopa cymbele* is predaceous on the leafhopper in Punjab. Ants like *Camponotus* and a spider *Distina albida* have also been reported to be predaceous on the insect.

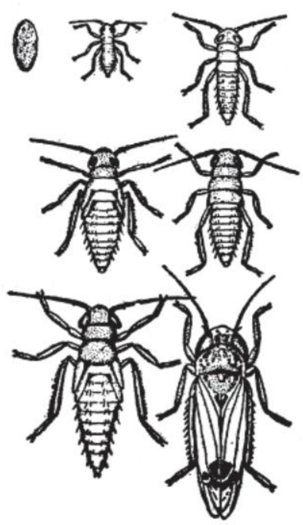
Control: Spray application of methyl parathion 0.025%, dimethoate 0.03%, methyl demeton 0.025%, etc. is recommended. Seed treatment with thiomethoxam 70 WS at 4 g/kg seed, imidacloprid 70 WS at 5-10 g/kg seed or carbosulfan 25 DS at 50 g/kg seed has been found effective. Foliar spray application of acetamiprid 20 SP at 10–15 g a.i./ha or carbosulfan 25 EC at 400–500 g a.i./ha or thiomethoxam 25 WG at 20–50 g a.i./ha or difenthiuron 50 SC at 300–400 g a.i./ha has also been found effective.

11. THE MANGO LEAFHOPPER *Amrasca splendens* (Fig. 57.22)

It has been reported to cause damage to mango leaves in Kerala.

Damage: Due to feeding by nymphs and adults on the undersurface of tender leaves brownish spots appear on midribs and veins and the leaves become curled and distorted.

Life history: The eggs are thrust into midribs or veins of tender leaves. The incubation period is three to four days. These are five nymphal instars occupying from seven to ten days. The leafhopper is greenish yellow with brownish markings on head, thorax and tegmen.



▲ **Fig. 57.22** *Amrasca splendens (M.R.G.K. Nair)*

Superfamily CERCOPOIDEA

Family Cercopidae (froghoppers or spittle bugs or cuckoo-spits)

Small jumping insects; measure rarely over 13 mm; usually brown or grey or sometimes variously coloured. Ocelli two; one or two stout spines present on hindtibiae and usually a series or circlet of spines at the apex; hindcoxa short and conical.

They feed on shrubs and herbaceous plants. The nymphs always remain inside a frothy spittle mass resting head downward on the plant and hence the name "spittle bugs" and this is a common sight in meadows and on grasses along rice fields. In each frothy mass one or more brownish or greenish nymphs can be seen. It leaves the spittle after the last moult and becomes active.

The fluid voided from the anus and the mucilaginous secretion from the epidermal glands on the seventh and eighth abdominal segments form the frothy mass. The caudal appendages aid in introducing air bubbles into the spittle. Spittle is not produced by adult. Economically the following species may be of some importance.

In the U.S.A. *Philaenus leucophthalmus* causes stunting in clovers. *Aphrophora paralella* and *A. saratogensis* are pests of pine. In India *Machaerota planitiae* occurs on ber (*Zizyphus* sp.), cotton, etc. *Clovia punctata* and *Poophilus costalis* have been reported to cause typical leaf yellowing in rice in India and Taiwan. They also occur on *Santalum album* in South India. *Phymatostetha deschampsi,* a brightly coloured black and blue species occurs on banana in South India. The other species from South India include *Clovia lineaticollis* and *Ptyelus* sp. which cause curling up of tender foliage of jack (*Artocarpus heterophyllus*). *Cosmoscrata relata*, a reddish large-sized species, swarms the branches of jack with frothy secretion.

Superfamily CICADOIDEA

Characterised by absence of sensilla on antennal pedicel and presence of sensory grooves on flagellum. Tegolae absent. Middle coxae short, hindcoxae mobile. The following families are important.

Family Cicadidae (cicadas)

Three ocelli placed near together and thickened anterior femora which is spined beneath are characteristic. Empodia are absent. In many cases the males have sound producing organs at the base of the abdomen.

Cicadas are large insects ranging from less than 25 mm to about 50 mm in length. They are well known in the United States as locusts, which is a misnomer; however, they are usually called as cicadas. About 1500 species are known from the warmer regions of the world.

Only males stridulate and the variation in note and the degree of intensity of the sound produced are so variable that each species can be recognised by the song. In India in the sub-Himalayan forests the songs of cicadas are said to be almost deafening and extremely monotonous. Sound is produced by a pair of organs situated on the ventral side of the basal abdominal segment. Each organ consists of a large plate, an operculum and a cavity containing the sound producing structures. Anteriorly in the cavity is present a yellowish membrane and posteriorly a shining "mirror' 'or tympanum. The lateral wall of the cavity is oval and ribbed and is known as tymbal. The song is produced due to the vibration of the tymbals effected by a muscle, and the other structures control the various characteristics of the sound produced. The females do not stridulate and may possess rudiments of the apparatus. The cicada with its ovipositor punctures or makes a slit on the twigs of shade, forest and fruit trees and thrusts its eggs. After an incubation period of about six weeks the nymphs hatch out from the eggs and drop to the ground. The nymphs have femora and tibiae of forelegs greatly enlarged and modified so as to enable them to burrow into the soil to a depth of about 50 cm and feed on the sap of roots of trees. In its last instar the nymph digs its way out of the ground, usually climbs to a tree and fastens its claws in the bark and moults. Adult may live a month or more. The life cycle may vary from one or two or more years depending upon the climate and the species involved.

In the U.S.A. two common types of cicadas, viz. the dog-day cicadas and the periodical cicadas are known. The dog-day cicadas appear each year because of the overlapping of broods and their life cycle may occupy two to five years as against 13 or 17 years in the periodical cicadas, the nymphs live underground for 13 or 17 years as the case may be. The periodical cicada *Magicicada septendecim* in the north eastern states of the U.S.A. requires 17 years to emerge and has 13 broods, the broods emerging in different years and have different geographic ranges. They emerge in May of the seventeenth year. The race in the south requires 13 years and has five broods. Considerable overlapping has been observed and in the same brood both life cycle types may occur, but emerge together only once every 221 years. The last instar nymph of the 17-year cicada under certain circumstances constructs a cone or chimney of about 10 cm high made up of earthen particles inside which it lives for several weeks before it becomes an adult. In the U.S.A. three species in each of the 17-year cycle and 13-year cycle cicadas occur.

Cicadas cause destruction in the following ways. Cicadas punctures twigs and sometimes even small trees are killed. The nymphs when they are found abundantly, in addition to sucking the sap from the roots of trees, honeycomb the soil and fruit growers at times incur appreciable loss. The adults also cause considerable damage to nursery stock and young trees.

Platypleura octoguttata, P. mackinoni, Pomponia fusca and *Huechys thoracica* are the species found in the plains of India.

GROUP FULGOROMORPHA

Superfamily FULGOROIDEA

Antennae arise from beneath the eyes on the sides of the head. Numerous sensillae are present on pedicel and a large sense organ is present on the basal segment of the flagellum. Recognised by presence of tegulae; midcoxae separated and elongated; hindcoxae immovable.

Following families are known:

Family Tettigometridae

About 70 species are known from Europe, Ethiopian region and Peru. *Hilda bengalensis* infests shoots of *Ficus religiosa.*

Family Cixiidae

No prolongation of head in front or only moderately so; carinae may be absent and if present a median carina evident on frons, distinct claval suture evident. Widely distributed but mostly tropical. In some the nymphs live underground and suck the sap from the roots of grasses. Wings transparent, frequently along the veins ornamented with spots. *Oliarus hodgarti* occurs on grasses in India.

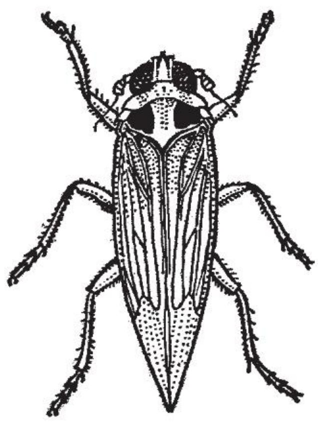
Family Delphacidae (Araeopidae)

This is the largest of the families of Fulgoroidea. The insects are characterised by large flattened spur at the apex of hindtibiae. They are generally small and many possess reduced wings. The leafhopper *Perkinsiella saccharicida* was once a serious pest of sugarcane in Hawaii. It is also serious on sugarcane in Queensland. *Perkinsiella sinensis* infests rice in India. The other important delphacid pests of crops in India are *Nilaparvata lugens* and *Sogatella furcifera* on rice and *Peregrinus maidis* on millets. Delphacids are commonly referred to as planthoppers.

1. THE WHITE-BACKED RICE PLANTHOPPER *Sogatella furcifera* (Fig. 57.23)

Distribution: Myanmar, Cambodia, Sri Lanka, China, Carolines, Marianas and Marshall Islands, India, Pakistan, Malaysia, Japan, Laos, Indonesia, Korea, Ryukyu Islands, Sabah, Philippines, Sarawak, Taiwan, Sakhalin in the U.S.S.R., Vietnam, northern territory of Australia, Fiji, New Hebrides, New Caledonia, Solomon Islands, New Guinea and Papua.

Damage: Plants infested by the planthopper show greenish yellow colouration of the leaves. Young seedlings die due to attack and in transplanted crop tillering may be delayed. In West Bengal it causes up to 80 per cent loss. In cases of severe infestation sooty mould develops. It is a vector of the rice yellow virus. In South India it is not serious on rice.



▲ **Fig. 57.23** *Sogatella furcifera*

Life history: The female inserts the eggs in the leaf sheath and midrib of leaves. The oviposition site is brown. A female lays up to 758 eggs in as many as 112 egg masses, each mass having 1 to 24 eggs. Egg measures about 0.8 to 1.2 mm long and 0.2 mm broad. Incubation period is six days. There are five nymphal instars occupying about 17 to 18 days. The total life cycle from egg to adult occupies from 23 to 24 days. The longevity of female is about two months. The adult has transparent wings with dark veins and tinted with brown. It measures about 3.5 to 4 mm long. Macropterous and brachypterous forms occur.

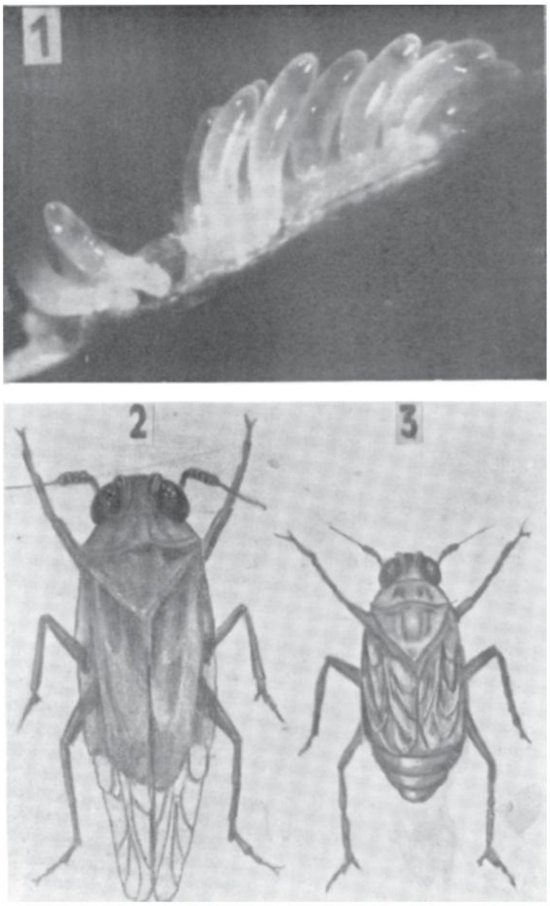
Host plants: Apart from rice it also infests sugarcane and other grasses such as *Panicum crusgalli, Alopecurus pratensis, Poa annua, Carex, Eleusine indica* and *Digitaria decumbens.*

Control: The control measures suggested for *Nephotettix nigropictus* may be followed.

2. THE BROWN-BACKED RICE PLANTHOPPER *Nilaparvata lugens* (Fig. 57.24)

Distribution: Extends from Japan, south through Oriental region, Micronesia and Australia.

Damage: It is a vector of rice grassy stunt virus. Nymphs and adults inject a toxic saliva at the time of feeding and suck the plant sap causing the development of rusty spots and lines which is followed by general drying of the tissues. In India it is very serious on rice and causes "hopper burn." In South India the *kuruvai* crop is severely infested at the shoot blade stage in August. Heavy build-up of population of the pest results in lodging of rice crop by September and heavy loss in yield. The crop will show a burnt up appearance with chaffy ears. In rare cases it occurs during January.



▲ **Fig. 57.24** *Nilaparvata lugens. 1 – Eggs, 2 – Macropterous adult, 3 – Brachypterous adult (T. R. Subramaniam et al., Rice Brown Planthopper Tamilnadu Agricultural University, Coimbatore, 1978)*

Life history: It is a brown planthopper measuring about 2.5 mm long in males and 3.3 mm in females. Brachypterous females measure 3.4 mm long. The female inserts the whitish, transparent, slender, cylindrical and curved eggs inside the leaf sheath tissue in two rows each group having 9 to 33 eggs. Eggs are also laid on either side of the midrib of the leaf sheath or in the fleshy basal portion of the midrib. The eggs are closely packed and glued together at one end. Eggs measure about 1.0 mm long and 0.2 mm broad. A female lays as many as 212 eggs. There are five nymphal instars. In South India the total life cycle of the insect has been found to be 20 days, the incubation and nymphal periods being 5 and 15 days respectively.

Host plants: Apart from rice, it infests *Cyperus rotundus* and *Panicum repens.*

Natural enemies: The aquatic bug *Gerris tristan* is predaceous on the insect. The coccinellid *Alesia discolor* is also partially predaceous on it.

Control: Application of malathion, phorate, acephate, carbaryl, fipronil, monocrotophos, etc. controls the pest.

3. THE CORN LANTERNFLY *Peregrinus maidis*

Distribution: Bermuda, West Indies, Micronesia, Philippines, India and East Africa.

Damage: It is one of the important sap feeders of millets in South India. It is known to be a vector of stripe disease of sorghum, maize, sugarcane, *Sorghum halepense, Setaria italica, Echinochloa colonum, Paspalum scrobiculatum* and *Pennisetum typhoideum.* On sorghum no marked injury is caused if population is less. In cases of severe attack the plants show unhealthy yellow appearance combined with stunted growth. Emergence of ears is prevented due to twisting of top leaves if attacked at shot blade stage. Honeydew excretion favours formation of sooty mould.

Life history: In both sexes macropterous and brachypterous forms are found. Macropterous forms possess transparent wings and the female is yellowish brown whereas male is dark brown. In the brachypterous forms the wings reach up to the sixth abdominal segment. The period from September to January is very conducive for the development of the insect. The nymphs and adults are semi-gregarious and are found on the leaves, leaf whorls and on the inner side of the leaf sheaths. The pre-oviposition period ranges from one to three days. The female makes a slit in the midrib of leaf and inserts the eggs in groups of one to four and covers them. In about seven days a female lays as many as 97 eggs. The egg is white, elongate, cylindrical and slightly tapering at the ends, the ends being quite blunt. It measures 1.29 mm by 0.35 mm. Egg cap is very prominent. The incubation period is seven to ten days. There are five nymphal instars which occupy about 16 days. The total life cycle ranges from 18 to 31 days. The ants *Camponotus compressus, Monomorium destructor*, *M. criniceps* and *Prenolepis longicornis* are found associated with the insect and feed on the honeydew excreted by it. Honeybees such as *Apis cerana, A. florea* and *Trigona irridipennis* collect the honeydew.

Host plants: *Sorghum vulgare, Oryza sativa, Zea mays, Pennisetum typhoideum, Sorghum halepense, Setaria italica, Echinochloa colona* var. *frumentacea, Paspalum scrobiculatum* and *Saccharum officinarum.*

Natural enemies: The bug *Cryptorhinus mundulus* is predaceous on the eggs of the insect.

Control: Carbaryl 0.1 % spray affords protection.

Family Derbidae

Tropical species with delicate wings and most species possess long wings. Terminal segment of rostrum is as long as wide. The insect *Proutista moesta* is prevalent commonly on sugarcane, maize, sorghum, grasses, *Arundo donax,* etc. in India.

Family Meenoplidae

A small family characterised by the presence of wax secreting poxes on sixth to eighth abdominal tergites. About 50 species are known from the Eastern hemisphere. Two species, viz. *Nisia atronervosa* and *Eponisia guttula*, are known to infest rice in India, the former being more predominant.

Family Kinnaridae

A small family recognised by the claval veins being formulate and apical segments of labrum much longer than wide. About 42 species are known. In Trinidad *Bytrois nemoralis* infests cacao.

Family Dictyopharidae

These are widely distributed medium-sized insects with a very much anteriorly prolonged head. About 500 species are known. On coffee, *Retiala viridis* has been reported as a minor pest. In India common species include *Dictyophara sauropsis*, *D. walkeri* and *Thanatodictya lineata.*

Family Fulgoridae

Tropical insects, which are large sized and brilliantly coloured; some of the largest individuals have a wing spread of 150 mm. Ocelli are two, rarely three or may be wanting. The three-segmented antennae terminate in filaments and they are inserted beneath the eyes. They are easily identified by the reticulate anal area of the hindwings. In some, peanut-like proboscis or prolongation in front of the head is a characteristic feature. This was believed to be luminous and hence the name lantern flies. But this has not been found true. Flocculent white wax is secreted by some species. In *Phenax* wax streams behind as long filaments as it flies. *Pyrops chennelli* is a common species in India. In South India swarms of *Fulgora delesserti* and *Kalidasa sanguinalis* are found on the bark of trees like *Ailanthus triphysa* and *Terminalia belerica.*

Family Flatidae

Widely distributed but mostly tropical. Generally large moth-like beautiful insects often delicately pigmented, wedge-shaped with wings held vertically at sides of the body at rest. Wings longer than body. Costal area of forewings with numerous crossveins. Nymphs are covered with long, curled, waxy filaments and often both nymphs and adults rest gregariously. Some species have two patterns of distinct colouration in their adult stage. Common Indian species are *Phromnia marginella, Lawana conspersa, Ketumala bisecta* and *Melicharia lutescens. Melicharia quadrata* is a pest on the ornamental plants, viz. *Zephyranthes vestita, Dahlia* sp., *Jasminum auriculatum*, *Eupatorium* sp. and *Notonia grandiflora*, and mango inflorescence. The pale green *Flata ocellata* is a pest on *Jasminum flexile, J. auriculatum* and *J. sambac.*

Family Acanaloniidae

Small group. Easily recognised by their shape. About 40 species known from America, Africa and the Indo-Malayan region. Spines are absent in hindtibiae except at the apex. Forewings very broad and wings held vertically at sides of the body at rest.

Family Issidae

A large and widely distributed family. Some possess short wings and a beetle-like snout; forelegs are enlarged with foliaceous femora and tibiae in *Angilia* and *Caliscelis.* Costa border without many cross-veins. Wings held less steeply at rest. *Sarina nigroclypeata* infests sandal trees in South India.

SANDAL TREE ISSID *Sarina nigroclypeata*

A common species found infesting both healthy and spiked sandal trees in Tamil Nadu and Karnataka States. Mass feeding by adults and nymphs causes death of sandal plants within three months. Shedding of foliage and destruction of the twigs and young shoots of a sandal branch are possible in two months due to attack by the bug. It is also responsible for the condition of stag-headedness in sandal. Honeydew excretion of the insect favours multiplication of sooty mould.

Life history: Mating takes place end to end lasting for two to three hours during the day time. Pre-oviposition period is about a week. Oviposition goes all round the year. The female lays the eggs singly or rarely in clusters of three or four on the bark of shoots, at the axil of leaf and shoot, on the petiole of the leaf, on old and new leaf blades and also on sprouting leaf buds. Incubation period varies from 7 to 25 days in different seasons. There are five nymphal instars, and the period from egg to adult occupies about 121 days. Longevity of adult varies from 93 to 107 days. There are three generations in a year and the generations overlap. The insect is active throughout the year in the sandal forests of Tamil Nadu and Kerala.

Host plants: Albizzia amara, Dodonaea viscosa, Erythroxylon monogynum, Lantana camara, Pterolobium indicum, Santalum album, Scutia indica and *Webera corymbosa*

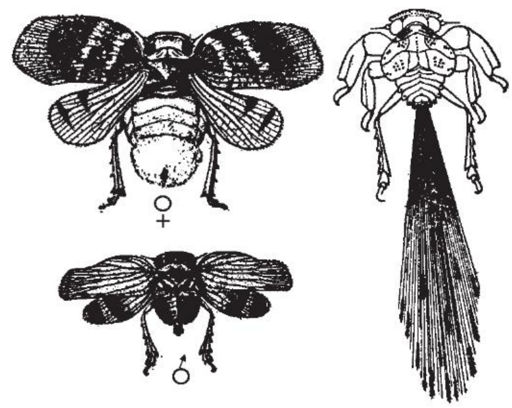
Family Ricaniidae

Tropical species mostly from Africa and the Oriental Region. Over 250 species are known. The insects are moth-like. Hindtrochanter is directed ventrally and possesses a short basal tarsal segment in the hindleg. Infestation on grass and rice by *Ricania zebra* is common. The brown *Ricania fenestrata* is a pest on *Jasminum flexile, Medicago sativa* and *Achras zapota.*

Family Eurybrachyidae

Eurybrachys tomentosa (Fig. 57.25).

A common plant hopper found on sandal and *Calotropis gigantea* in South India. On sandal the early instar nymphs suck up the sap from tender green shoots and the later two instar nymphs and adults suck sap from green shoots. Due to feeding growth is retarded, and the foliage may be shed. This species is also partly responsible for stagheadedness generally prevalent in sandal forests.



▲ **Fig. 57.25** *Eurybrachys tomentosa: female, male and nymphs*

Life history: Adult lives for over two months and the females have a long oviposition period. Pre-oviposition period is 10 days. Eggs are laid on the leaves and shoot of sandal and the egg clusters are covered with a thick mat of white flocculent efflorescence by the female. Each cluster contains 30-42 eggs and a female lays as many as six egg clusters. Incubation period is 15 to 21 days. There are five nymphal instars. Life cycle ranges from 109 to 132 days and on an average development from egg to adult takes about 120 days. There are three overlapping generations in a year. The female is larger and greenish olivaceous, whereas the male is smaller with tawny brown tegmina.

Host plants: *Albizzia lebbek, Argyreia cuneata, Cassia fistula, Cipadessa fruticosa, Elaeodendron roxburghii, Santalum album, Scutia indica, Terminalia tomentosa, Vitex negundo, Vitis* sp., *Zizyphus jujuba, Z. oenoplia, Z. xylopyra, Abelmoschus esculentus, Calotropis gigantea, Hibiscus,* cotton, *Erythrina lithosperma, Cajanus cajan, Crotalaria paniculata* and *Dichrostachys cinerea.*

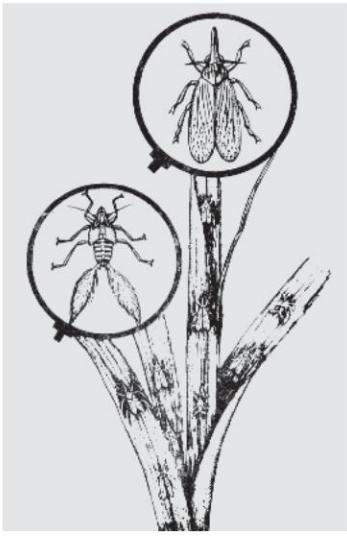
Family Lophopidae

Oriental species. Over 50 species are known. Characterised by hindtrochanters directed backwards and a moderately long basal segment in the hindtarsi. Includes *Pyrilla* sp., *Elasmoscelis platypoda* and *Lophops carinatus.*

SUGARCANE LEAFHOPPER *Pyrilla perpusilla* (Fig. 57.26)

Distribution: It is one of the important pests of sugarcane in Uttar Pradesh, Bihar, Punjab and Maharashtra; occasionally flares up on sugarcane in Tiruchirapalli and North Arcot districts of Tamil Nadu during monsoon season.

Damage: Both the nymphs and adults remain in colonies on the undersurface of leaves and suck the sap causing yellowing and withering of leaves. Honeydew excretion of the insect favours development of sooty mould on leaves. Growth of the plant is suppressed and when terminal buds are affected, lateral sproutings may take place. In years of epidemic, the insect is capable of decreasing sugar and gur recovery to the extent of 50 per cent.



▲ **Fig. 57.26** *Sugarcane pyrilla Pyrilla perpusilla*

Life history: The adult insect is brown with a conspicuously long pointed snout and the wings are densely veined and transparent. It is active from March and by September-October causes appreciable damage to sugarcane crop. The female plant hopper lays the yellowish eggs in clusters on the underside of leaves or inside leaf sheaths and covers them with white fluffy waxy filaments. The number of eggs in each egg mass may vary from 19 to 58. When the infestation is severe the eggs may be laid anywhere indiscriminately. A female lays 600-800 eggs and the incubation period during summer, monsoon and winter months ranges from 10–15, 6–10 and 15–18 days, respectively. The nymph is pale brown with two long filaments in the anal region and is covered with white wax. The total nymphal period during summer, monsoon and winter months ranges from 40–52, 34–40 and 70–132 days, respectively. In a year there may be three or four generations. Continuance of life is carried out by eggs which are found under sheathing leaves during the winter. The insect breeds profusely in soft canes which grow luxuriantly and possess broad, succulent drooping leaves and loose leaf sheaths. Prevalence of easterly winds and high atmospheric humidity during May-June and high humidity coupled with low maximum temperature during summer and low rainfall or long dry intervals during monsoons have been found to favour heavy incidence of the insect on sugarcane.

Host plants: Apart from sugarcane it infests wheat, rice, barley, oats, maize, sorghum, *Pennisetum typhoideum,* Napier grass *(P. purpureum),* bamboo, wild grasses, *Trifolium alexandrinum, Pisum sativum, Cicer arietinum,* etc.

Natural enemies: Ageniaspis pyrillae, Cheiloneurus pyrillae, Ooencyrtus papilionis, O. pyrillae (Encyrtidae), *Tetrastichus pyrillae* and *Syntomosphyrum udaipurensis* (Eulophidae) are egg parasitoids of the insect. *Chlorodryinus pallidus, Dryinus pyrillae, Pseudogonatopus pyrillae* and *Lestodryinus pyrillae* (Dryinidae) are parasitic on nymphs. On adults the larvae of the lepidopteran insect *Epiricania melanoleuca* (Epipyropidae) is ectoparasitic. The stylopid *Halictophagus compactus* is parasitic on nymphs and adults. The predators include *Brumoides suturalis, Coccinella septempunctata, Cheilomenes sexmaculatus, Verania allardi* (Coccinellidae) and *Chrysopa scelestis* (Chrysopidae). The fungus *Metarrhizium anisopliae* also infects *Pyrilla.*

Control: Leaves with colonies of nymphs and egg masses may be collected and destroyed. Burning the trash after harvest is also suggested. Spray application of malathion 0.05% or endosulfan 0.07% is suggested. Release of 8000 to 10000 cocoons or 8 to 10 lakh eggs of the lepidopteran *Epiricania melanoleuca* in states like Gujarat, Haryana, Uttar Pradesh and Maharashtra has given effective control of the pest.

SERIES STERNORRHYNCHA

The following superfamilies have been recognised in this series: 1. Psylloidea, 2. Aleyrodoidea, 3. Aphidoidea, and 4. Coccoidea.

Snperfamily PSYLLOIDEA

Characterised by possession of mouthparts and two pairs of wings in both the sexes; forewings rather harder in consistency than hindwings. Antennae usually 10-segmented. Tarsi two-segmented with paired claws, femora thickened.

Family Psyllidae (jumping plant lice)

Psyllids are very small active insects measuring about two to five mm in length. They possess relatively long antennae and three-segmented rostrum. The hindlegs are stronger than the other legs and at the slightest disturbance they jump out quickly. They rest on plants in a characteristic way with the body raised up and the head almost touching the surface. The nymphs in general are flat. Many species in their nymphal stages produce white waxy secretions. They are phytophagous and most species are host specific.

In the U.S.A., the psyllid *Paratrioza cockerelli* is a vector of the virus disease termed psyllid yellows in potato, tomato, pepper and eggplant. In India psyllids are common and only a few are economically important. The pear psyllid *Psylla mali* on pear and the citrus psyllid *Diaphorina citri* on citrus and *Murraya koenigii* are important pests. A number of species have also been reported to cause simple and compound galls on various plants. Galls are produced by *Pauropsylla depressa* on *Ficus glomerata* and *Megatrioza vitiensis* on *Sygzigium jambolanum.*

1. THE PEAR PSYLLA *Psylla mali*

Distribution: It is a pest on apple in England and the U.S.A and has a limited distribution in the U.S.A. In India it is a pest on pear on the Kodaikanal and Nilgiris hills in Tamil Nadu.

Damage: It is one of the important pests of pear in Tamil Nadu. Nymphs and adults infest heavily the leaves and tender buds and suck the sap. Due to heavy drain of cell sap the leaves get malformed, turn brown and often drop. The normal growth of young tree is impaired. Honeydew excretion promotes sooty mould development on the leaves and fruits.

Life history: The adult is brownish with a reddish tinge, cicada-like and possesses two pairs of membranous wings. The female lays lemon yellow eggs neatly arranged on either side of the midrib of tender leaves as also on the leaf stalk. The egg is elongated and to its slightly tapering end a threadlike filament is attached. Incubation period is from five to eight days. The newly hatched out nymphs are light yellow which in due course become light green and later light brown as they grow in size. There are five nymphal instars. The last instar nymph is dark brown in colour with reddish wing pads and measures about 1.5 mm long. The nymphal period varies from 18 to 30 days. The female measures about 2.5 mm long as against 2.0 mm in the male. The total life cycle from egg to adult occupies about 25 to 36 days during September-December on the Kodaikanal hills. The longevity of the adult is about 13 to 15 days. The population of the insect on pear trees is high during February to May but after September its population dwindles.

Control: Malathion 0.05 % spray application controls it.

2. THE CITRUS PSYLLA *Diaphorina citri*

Distribution: Throughout the Oriental region and all over India.,

Damage: It is a serious pest of citrus and curry leaf (*Murraya koenigii*) in India. Nymphs and adults suck the sap from the tender leaves and shoots and cause defoliation and death of the shoots and ultimate drying up of the branches. Honeydew excretion of the nymphs favours multiplication of sooty mould on the leaves.

Life history: The adult is brownish and measures 2.4 mm long. They remain mostly on the undersurface of leaves with their heads almost touching the surface and the rest of the body raised up. Soon after becoming adults copulation takes place. The male holds the female with the legs of one side and supports itself with the legs of the other side, the heads pointing in the same direction. Eggs are laid soon after mating in the folds of half opened leaves and axils of leaves or pushed in between buds and stem or petioles of leaves and axillary buds. They may also be laid scattered on the upper or lower surfaces of leaves, tender stem, etc. About 800 eggs may be laid by a female. Oviposition period lasts for about two months. The egg is orange coloured, elongate, thicker at the basal end and anteriorly it is slightly curved and tapering. From the basal end a stalk arises by which it is anchored to the plant tissues. Incubation period is four to six days in summer and up to 22 days in winter. There are five nymphal instars. They are light yellow with an orange tinge in the region of the abdomen. Nymphal period is about 11 to 25 days. The total life cycle occupies from 15 to 47 days depending on seasonal conditions. Adult longevity is about 189 days. The insect is active from February and increases during March-April. It disappears by about the middle of October. In a year there are about nine generations.

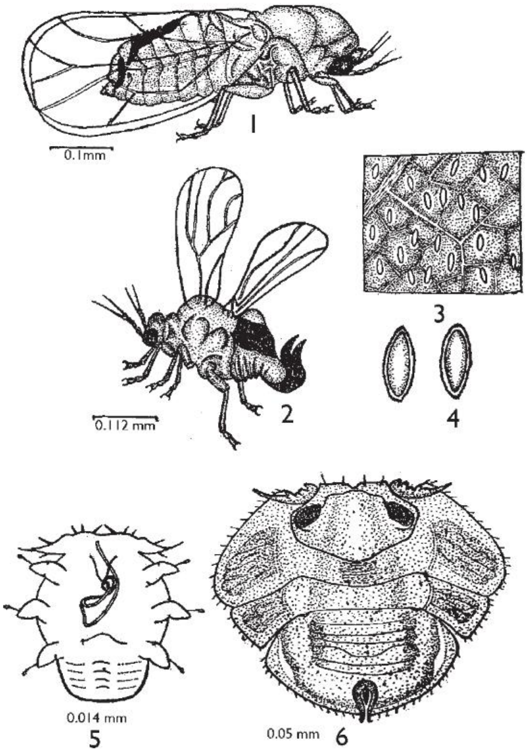
Host plants: In Punjab it attacks *Citrus aurantium* (orange), *C. medico limonium* (lemon), *C. medica lunetta* (sweet lime), *C. medico acida* (sour lime), C. *medico medico* (citron), *C. decumana* (Pomello) and *Murraya koenigii.*

Natural enemies: *Coccinella septumpunctata*, *C. repanda, Cheilomenes sexmaculatus, Chilocorus nigritus, Brumoides suturalis* (Coccinellidae) and *Chrysopa* sp. (Chrysopidae) are predaceous on the nymphs of the insect. *Tetrastichus radiatus* is parasitic on the nymphs.

Control: Spraying malathion, fenitrothion, phosphamidon, dimethoate, etc. affords relief.

3. THE MANGO PSYLLID *Pauropsylla brevicornis* (Fig. 57.27)

This is a serious pest of mango in Kerala since 1970 and has also been reported from Dehra Dun (Uttar Pradesh). The adult female measures 5.8 mm long and has a greenish



▲ **Fig. 57.27** *Different stages of Pauropsylla brevicornis Crawford. 1. Adult female, 2. Adult male, 3. Eggs in leaves, 4. Egg, 5. First instar nymph 6. Fifth instar nymph (After S. Chandrika and M.R.G.K. Nair, Entomon)*

yellow abdomen with black tergal sclerites and deep brown head and thorax. The male measures 3.08 mm long and its abdomen is slender and deeper coloured. The female thrusts its oval egg singly inside the leaf tissue and the incubation period varies from eight to nine days. There are nymphal five instars and the nymphal period varies from 19 to 24 days. They cluster on tender stems, leaf stalks and leaf veins and cause withering and drooping of leaves and sooty mould development on leaves on which the honeydew excreted by them fall.

Superfamily ALEYRODOIDEA

Family Aleyrodidae (whiteflies)

The Aleyrodoidea consists of a unique small family Aleyrodidae, commonly called whiteflies or aleyrodids. The name *Aleyrodes* was unnecessarily altered by Burmeister in

1835 to *Aleurodes* and, therefore, both the names were in use. The whiteflies are small inconspicuous insects. They are primary restricted to the tropics and subtropics but a few are found in cooler regions also. All species live on the leaves of plants, mostly on the undersurface, and a few of them are economically important. This family is represented by two subfamilies viz. Aleurodicinae and Aleyrodinae in India.

The aleyrodids are small insects with seven-segmented antennae, two ocelli and a pair of reniform compound eyes. Wings are of equal consistency, opaque, whitish, clouded or mottled with spots or bands. Rostrum is three-segmented. Tarsi are two-segmented terminating into pad like empodium or spine in between the claws. Male genitalia with a pair of prominent claspers and in the female an acute ovipositor is present. The insects are oviparous and the eggs are stalked. There are four nymphal instars. In most cases the first instar nymph is mobile and in the subsequent two instars it is immobile and attaches itself to its host. The fourth instar is also a stationary one and is called the "puparium". The adult emerges by means of a **T**-shaped rupture of the dorsal wall of the puparium.

The puparial or pupal case is the one primarily used for taxonomic study as it exhibits multitiude of characters. The unique structure is the vasiform orifice. It is an opening found on the dorsal surface of the last abdominal segment in which is situated an operculum. A tongue-shaped lingula is present beneath the operculum and may either be covered by the operculum or may project beyond it. At the base of the lingula is the opening of the anus through which honeydew is excreted. Like aphids, some aleyrodids such as *Neomaskellia bergii* and *Rhachisphora trilobitoides* are also attended to by ants for their honeydew. Varying amounts of waxy secretions are produced from papillae or simple or compound pores of the nymphs and puparia of most species.

Sexual reproduction is the general rule but parthenogenesis occurs to some extent. Males develop from unfertilised eggs whereas from fertilised eggs both the sexes develop. In the green house whitefly *Trialeurodes vaporariorum* an American race and an English race exist. When it reproduces partheno-genetically American race gives rise to males whereas English race produces females. From fertilised eggs individuals of both the sexes are produced.

Prevalence of host-correlated variation in aleyrodids and its bearing on the taxonomy of aleyrodids are very important aspects to be considered. Frequently due to lack of knowledge of such variations it may be possible to recognise two slightly different forms of an insect as two distinct species when they occur on two different hosts. *Trialeurodes vaporariorum* and *Bemisia tabaci* show variation in structures like papillae, pores, setae, etc. These forms have associations with definite types of host leaves such as hairy specimens on hairy leaves and glabrous specimens on glabrous leaves.

Subfamily ALEURODICINAE

The species representing this subfamily noticed in India are *Aleurodicus dispersus, A. holmesii, A. indicus* and *A. machili,* of which *A. dispersus* has become a serious pest on a large number of agricultural and horticultural crops and forest trees since 1993.

1. THE SPIRALLING WHITEFLY *Aleurodicus dispersus* (Figs 57.28 and 57.29)

This polyphagous species is widely distributed in many parts of the world including India, Maldiv Islands, Sri Lanka and Thailand, and was first reported to occur in India in 1995 on tapioca and other cultural crops. Since then it has become a pest of importance in the southern part of the country infesting more than 200 plants. Its infestation debilitates the plants due to extensive draining of sap and also development of sooty mould on the honey dew excreted by the nymphs which falls on the leaves and fruiting bodies.

The adults are bigger in size and the males are recognised by the distinct elongate claspers. The eggs are inserted into the stomata on the under surface of leaves in the form of loose spiral of wax deposits derived from the abdomen of the female. A female lays on an average 16 eggs and the incubation period ranges from four to ten days. The nymphal period lasts for 12 to 33 days. Marginal fringes of wax and deposits of powdery wax on dorsum and the glassy wax filaments from the compound pores are very characteristic. The total developmental period varies from 21 to 30 days. It has been noticed to be a serious pest of guava, tapioca, etc.

▲ **Fig. 57.28** *Aleurodicus dispersus. Top – Nymph with dense waxy covering Bottom – Adults (courtesy : R. Sundararaj)*

▲ **Fig. 57.29** *Heavy infestation of Aleurodicus dispersus on Euphorbia pulcherimma (ibid)*

Its important hosts being guava, papaya, mulberry, *Syzigium jambolanum, Tectona grandis, Thespesia populnea, Michelia champaca, Euphorbia pulcherimma, Eucalyputus camaldulensis, Artocarpus heterophyllus, Bauhinia variegata, Pongamia glabra, Polyalthia longifolia,* etc.

The natural enemies include the parasitoids *Encarsia ?haitiensis* and *E. guadeloupae* and the predators *Cryptolaemus montrouzieri, Axinoscymnus puttarudriahi, Scymnus coccivora, S. nubilus, Cheilomenes sexmaculatus, Chilocorus nigritus, Pseudaspidimerus trinotatus* and *Serangium parcesetosum* (Coccinellidae), *Cybocephalus* sp. (Nitidulidae), *Chrysoperla carnea, Apertochrysa* sp., *Mallada astur* and *M. boninensis* (Neuroptera), and *Acletoxenus indicus* (Drosophilidae : Diptera).

Control: Spray application of malathion 0.1% or neem oil 0.3% or the insect growth regulator diflufenthiuron 0.012% minimises severity of infestation.

Subfamily ALEYRODINAE

In India, *Bemisia tabaci* on cotton and tobacco, *Neomaskellia bergii* and *Aleurolobus barodensis* on sugarcane, *Aleurocanthus spiniferus* on rose, *Aleurocanthus woglumi* on Citrus, *Aleuroclava psidii*, *Rusostigma eugeniae* on *Syzigium*, *Trialeurodes ricini* on castor and *Phyllanthus acidus*, and *Siphoninus phillyreae* on pomegranate are some common and important pests. *Bemisia tabaci* is a well known vector of the tobacco leaf curl and a few other virus diseases of crops. The same insect on *Achyranthes aspera*, a common weed, produces beautiful scarlet red galls in patches on the undersurface of leaves. Species belonging to the genus *Gomonella* live in pits on leaves. *Rusostigma eugeniae* causes characteristic punctations on both the surfaces of leaves, but more often on the dorsal surface in *Syzigium jambolanum*.

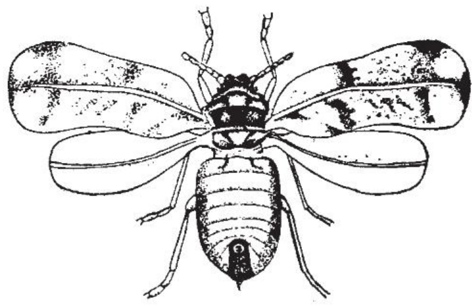
The following are some important aleyrodids of India.

1. THE SUGARCANE ALEYRODID *Aleurolobus barodensis* (Fig. 57.30)

Distribution: Throughout India and in Pakistan, Taiwan, Philippines, Java, Malaysia, etc.

Damage: It is primarily a pest of sugarcane.

The nymphs suck the sap and in cases of severe infestation retard the growth of sugarcane plants. Sugar recovery is also affected considerably.



▲ **Fig. 57.30** *Adult of Aleurolobus barodensis (Fletcher)*

Life history: The adult is pale-yellow with white mealy wings. Copulation takes place soon after emergence. Soon after pairing the female lays the eggs on the undersurface of the lower half of the leaves in linear rows. A female lays in a row about 15 to 20 eggs and as many as 52 eggs are laid by an individual. The egg is creamy yellow with a small curved stalk when freshly laid but soon it turns black. Incubation period ranges from eight to ten days. The first instar nymph is oval, pale yellow and bears three pairs of legs, a pair of compound eyes and a pair of ocelli. It wanders for some time, settles on the undersurface of leaf and starts sucking the sap. During this period the colour changes to shiny black and the entire margin is surrounded by fringes of wax. On either side of the mid-dorsal line white waxy specks can be seen. There are three nymphal instars occupying a developmental period of 15 to 30 days. The fourth puprial stage lasts for 10 to 15 days. The total period from the hatching of the eggs to emergence of adults takes about 25 to 47 days. In winter it is prolonged to 119-130 days. The longevity of the adults is about one or two days. Parthenogenesis has not been noticed in the species. Ants and the chalcid parasite *Azotus delhiensis* feed on the honeydew excreted by the nymphs. The whitefly occurs abundantly under conditions of drought, deficiency in nitrogen, water logging, heavy rains, ratooning of canes, inadequate manuring and alkalinity of soil.

Host plants: *Enianthus aundinaceum*, *E. ciliaris, Saccharum spontaneum* and sugarcane.

Natural enemies: *Azotus delhiensis, A. pulchriceps, Encarsia isaaci, E. muliyali* (Aphelinidae), *Amitus aleurolobi* (Platygasteridae), *Cardiogaster secundus*, *Syntomosphyrum* sp. (Eulophidae) and *Baryscapus* sp. (Eulophidae) are parasitic on the insect. The preadators include *Cheilomenes sexmaculatus, Brumoides suturaalis, Chilocorus nigritus,* and *Verania discolor* (Cocinellidae). A fungus *Aschersonia placenta* is parasitic on the aleyrodid nymphs.

Control: Discourage ratooning in low lying areas and avoid water logging. Remove lower leaves containing pupae periodically and destroy. Spray application of endosulfan 0.10% or malathion 0.10% or monocrotophos 0.05% minimises damage.

2. THE SUGARCANE SPOTTED ALEYRODID *Neomaskellia bergii*

Distribution: Throughout India, Sri Lanka, Australia, Bangladesh, Japan, Java, Mauritius, Fiji, Levuka, Philippines, Reno Manila, Samoa, San Thome, South Africa. etc.

Damage: It is a pest on sugarcane. Nymphs suck the sap and in cases of severe infestation may cause stunting of canes. In the case of sorghum severe infestation results in complete drying of leaves and ultimate death of young plants. In the later stage of the crop ears are formed with ill-filled grains.

Life history: The aleyrodid is pale brown with wings having black markings. Mating takes place end to end. The eggs are laid on the undersurface of leaves in concentric semicircles. Freshly laid eggs are pale yellow which in due course turn dusky yellow. Oviposition period is about three days. In a group there may be 100 to 150 eggs or more. The egg is attached to the leaf by a pale brown stalk. The nymph is pale brownish to dark in colour surrounded by a palisade of white wax which raises it from the leaf surface. The period from egg to emergence of adult varies from 19 to 22 days. The nymphs are attended by ants like *Camponotus compressus* and *Cremastogaster* sp.

Host plants: Sugarcane (*Saccharum officinarum*) and *Sorghum vulgare.*

Natural enemies: *Scymnus* sp. is predaceous and *Eretmoceras delhiensis, E. mundus* (Aphelinidae), *Encarsia neomaskelliae, E. tristis* (Aphelinidae) and *Aphidencyrtus* sp. (Encyrtidae) are parasitic.

Control: Same as for *Aleurolobus barodensis.*

3. THE CASTOR ALEYRODID *Trialeurodes ricini*

Distribution: Throughout India, Thailand, Cameron, Central African Republic, Sudan, Uganda, Israel, Iran, Saudi Arabia, etc.

Damage: This is primarily a pest on castor (*Ricinus communis*). The nymphs suck the sap from the undersurface of leaves in large numbers as a result of which the leaves show yellow patches. Honeydew excretion favours multiplication of sooty mould. In young plants severe infestation results in gradual drying of leaves and ultimate death of the plants.

Life history: The adults are pale yellow with white wings covered with waxy powder. The female prefers tender leaves for oviposition. The eggs are laid in clusters or scattered on the undersurface of leaves. The nymphs are light, translucent yellow in colour and entire margin encircled by a broad fringe of closely set thick waxen filaments.

In South India it occour on castor almost throughout the year but is severe during March-June. Infestation is light during November-January and thereafter increases gradually. Observations have also shown that castor varieties with double and triple blooms are very highly susceptible to attack by the insect.

Host plants: *Ricinus communis, Annona glabra, Aristolochia bracteata, Breynia rhamnoides, Gossypium hirsutum, Moringa oleifera, Phyllanthus acidus* and *Achras zapota.*

Natural enemies: The coccinellids *Cryptognatha flavescens, Brumoides suturalis* and *Sticholotis* sp., a drosophilid fly *Acletoxenus indicus* and the lygaeid bug *Geocoris tricolor* are predaceous on the nymphs of the aleyrodid. *Prospaltella* sp. and *Aphelinus fuscipennis* are parasitic. *Encarsia isaaci, E. lahorensis, E. transvena* and *Eretmocerus mundus* (Aphelinidae) are also parasitic on this species. In Coimbatore the fungi *Spicaria* sp. and *Cladosporium* sp. have been reported to be parasitic on the aleyrodid.

Control: As for sugarcane aleyrodid.

4. THE COTTON WHITEFLY *Bemisia tabaci* (Fig. 57.31)

Distribution: Throughout India, Sri Lanka, Nigeria, Congo, West Africa, U.K., Spain, Morocco, Libya, Greece, Egypt, Israel, Iran, Urussia, Japan, etc.

Damage: It is a serious pest of cotton in Northern India. Under conditions of moderate attack premature defoliation is common. In cases of severe infestation sooty mould development is clear due to honey-

▲ **Fig. 57.31** *Bemisia tabaci*

dew excreted and bud shedding and bad opening of the bolls are directly proportional to the intensity of whitefly attack. Apart from cotton, being a polyphagous species, it breeds on a large number of plants. It is a vector of leaf curl virus on tobacco, cassava, cotton, etc.

Life history: Its life history on cotton has been extensively studied in Punjab. The female lays the eggs almost invariably on the undersurface of leaves, mostly on the top and middle leaves of a plant. Oviposition period ranges from 2 to 12 days. Incubation period ranges from 3 to 33 days, i.e. 3 to 5 days in April-September, 5 to 17 days in October-November, 7 to 16 days in February-March and 33 days in April-September and from October onwards ranges from 17 to 73 days. The puparial stage occupies 2 to 8 days. A complete life cycle from egg to adult may occupy 14 to 107 days, i.e. 14 to 21 days during April-September and the longest period during November-February. During summer, longevity of adults is about two to five days and during winter up to 24 days. Parthenogenesis is very common. The maximum infestation on cotton occurs during July-August. About 12 generations may be noticed in a year.

Host plants: Cotton (*Gossypium* sp.), *Althaea rosea, Corchorus tridens, C. trilocularis, Abelmoschus esculentus, Sida cordifolia, Brassica oleracea* (cabbage), *Brassica rapa, B. campestris* (rape seed), *B. napus* var. *dichotoma* (Indian rape), *Raphanus sativus, Cucumis malo* (melon), *Citrullus vulgaris* (water melon), *Citrullus colocynthis, Cucumis sativus* (cucumber), *Lagenaria vulgaris* (gourd), *Cucumis pubescens, Momordica charantia, Crotalaria juncea, Cyamopsis tetragonoloba, Melilotus parviflora, Euphorbia pilulifera, E. prostrata, Phyllanthus sp., Datura alba, Capsicum frutescens* (chillies), *Nicotiana tabacum* (tobacco), *Solanum nigrum, S. melongena, S. tuberosum* (potato), *S. xanthocarpum, Eclipta erecta, Sonchus oleraceus, S. arvensis, Carthamus tinctorius, C. oxycantha, Boerhaavia diffusa, Celosia* sp., *Achyranthes aspera, Digera arvensis, Chenopodium album, Convolvulus arvensis, lpomoea* sp., *Cleome viscosa, Pisum sativum, Linum usitatissimum, Medicago denticulata, Coriandrum sativum, Physalis peruviana, Trichosanthes dioica, Lamia asplenifolia, Lippia geminata, Trewia nudiflora, Nyctanthes arbortristis, Clerodendron infortunatum, Zinnia elegans, Lablab niger, Ageratum conyzoides, Manihot utilissima* (tapioca), etc.

Natural enemies: The important parasitoids exercising natural control of this whitefly pest is *Eretmocerus mundus* and *Encarsia brevivena, E. formosana, E. lutea, E. smithi, E. transvena* (Aphelinidae). The predators noticed are *Chrysopa* sp. (Neuroptera) and *Brumoides* sp. (Coleoptera). The fungus *Paecilomyces fumasoroseus* effectively kills the adults.

Control: Spray application of acephate 0.075% or profenofos 0.05% or phosalone 0.07% + neem oil 0.3% or phosalone 0.07% + ethion 0.10% controls the pest appreciably. Seed treatment with thiomethoxam 70 WS at 4 g/kg seed, imidacloprid 70 WS at 5-10 g/kg seed or carbosulfan 25 DS at 50 g/kg seed has been found effective. Foliar spray application of acetamiprid 20 SP at 10-15 g a.i./ha or carbosulfan 25 EC at 400-500 g a.i./ha or thiomethoxam 25 WG at 20-50 g a.i./ha or difenthiuron 50 SC at 300-400 g a.i./ha has also been found effective.

5. THE CITRUS ALEYRODID *Dialeurodes citri* (Fig. 57.32)

Distribution: India, Japan, China, Florida, California and some other parts of the U.S.A., Chile, Mexico and Brazil.

Damage: In India it is a serious pest on citrus in Assam, Nagpur, Poona, Dehra Dun, Saharanpur, Bihar and the Punjab. Though no visible damage is seen due to infestation by the pest, sooty mould development due to the honeydew excreted by the insects is very conspicuous.

▲ **Fig. 57.32** *Dialeurodes citri (1-2: Adults, eggs and larvae) Aleurocanthus woglumi (3-5: Adults, egg mass and larvae & sooty mould) (Bayer A. G., Crop Protection Compendium, 1968)*

Life history: The eggs are laid singly, irregularly scattered on the lower surface of leaves. A female lays as many as 201 eggs. Oviposition period is about four days. The egg is subelliptical, pale yellow and stalked. It measures 0.23×0.10 mm. The egg period varies from 10 to 12 days in the first brood and 7 to 13 days in the second brood. There are three nymphal and one pupal instars. The puparium is sub-elliptical or broadly oval, pale yellow with an orange or yellowish area in the middle. Female puparium measures 1.5×1.2 mm and male puparium 1.08×0.76 mm. The duration of the nymphal and puparual periods respectively during the summer varies from 25 to 51 days and 125 to 154 days and during the winter from 49 to 71 days and 114 to 159 days. The pre-imaginal period is 177 to 190 days in the summer brood and 181 to 205 days in the winter brood, the greater part of the time being spent in the pupal stage. The adult is pale yellow with powdery wax dusted on it. The longevity of the adult is about two to eight days. There are two distinct broods in Punjab. The first brood comes out in March-April and the second brood in August-September. From October-February only pupae are seen. In Florida three broods in a year are noticed.

Host plants: *Citrus* spp. (orange, malta leaves, sour lime, lemon).

Natural enemies: *Prospaltella lahorensis* is parasitic on the insect.

Control: As for *A. barodensis*.

6. THE CITRUS BLACKFLY *Aleurocanthus woglumi* (Figs 57.32 and 57.33)

Distribution: India, Sikkim, Sri Lanka Philippines, Jamaica, Kingston, Cuba, Bahamas.

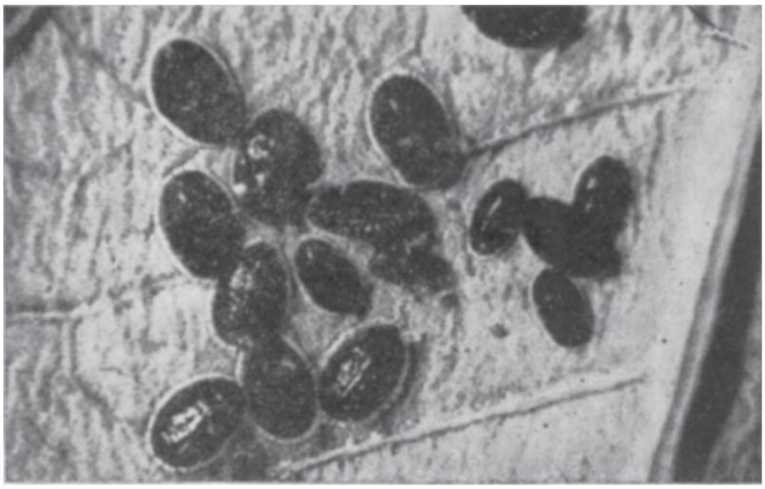
Damage: It is a serious pest on *Citrus* spp., especially oranges. Damage as in the case of *D. citri*. In South India often causes serious damage to *Murraya koenigii*.

Life history: Eggs are laid in a spiral and the egg spirals are always of three whorls as against a spiral of one whorl in *A. husaini*. A spiral contains 15 to 22 eggs and a female lays one to three spirals in her life time. On a broad citrus leaf as many as 3000 eggs are laid. The egg is slightly reniform-elliptical, measures 0.26 by 0.01 mm, and has yellowish brown colour. Surface marked with hexagonal or polygonal markings. Incubation period varies from 7 to 14 days. Nymphal period varies from 38 to 60 days depending on the weather conditions. Puparial period usually varies from 100 to 131 days but during winter ranges from 147 to 161 days. The puparium is oval, black in colour, dorsum arched with long black spines, margin with rounded black teeth and measures 1.4 by 0.88 mm. Exuviae of the third instar lie on the dorsum. The adult is dark orange with smoky wings and forewings having four whitish areas of irregular shape. There are two distinct broods in a year. The first brood adults emerge in March-April and those of the second brood emerge in July-October and sometimes in November also.

Host plants: *Citrus* spp. (oranges, maltas), *Morinda tinctoria* and *Murraya koenigii.*

Natural enemies: The hymenopterous insects parasitic on the insect are *Prospaltella divergens, Encarsia bennetti, E. longifasciata, E. merceti, E. opulenta, E. smithi, E. tinctoriae, E. transvena, Eretmocerus serius* and *Ablerus inquirenda* in India, *Ablerus macrochaeta* in Singapore and *Ablerus connectens* in Sri Lanka.

Control: As for *A. barodensis*



▲ **Fig. 57.33** *The citrus blackfly Aleurocanthus woglumi on Morinda tinctoria leaf*

7. THE ASH WHITEFLY OR POMEGRANATE WHITEFLY *Siphoninus phillyreae*

It has a world wide distribution and is evident throughout much of Europe, northern Africa, and the Middle East and also from Greece, Bulgaria and Los Angeles and California in the USA. It is commonly known as the ash whitefly causing serious damage to ash *Fraxinus* spp.

It infests the under surface of leaves causing appearance of chlorotic spots and shedding of leaves. On the honeydew excretion of the nymphs, which fall on leaves, black sooty mould develops which interferes with photosynthetic activity. At times it is considered to be a serious pest of pomegranate (*Punica granatum)* in India and ash *(Fraxinus* spp.) in other parts of the world, particularly USA. In India it also infests *Prunus persica* and *P. communis.*

Copulation takes place from side to side which lasts for 15 minutes. The female thrusts its proboscis in the leaf tissue and keeping it as a pivot moves in the form of a circle and commences egg laying. A female lays on an average 45 cream coloured eggs in clusters, each cluster having 4 to 26 eggs. The egg is inserted into leaf tissue by a pedicel and dusted all over with powdery wax . Egg measures 0.33 mm long. There are four nymphal instars, the fourth being the puparium. The adult emerges through a longitudinal slit on the cephalo-thoracic region of the puparia. The life cycle takes 17 to 20 days and about eight generations in a year.

Natural enemies: In India the parasitoid *Encarsia inaron* (Aphelinidae) and the predators *Clania* sp., *Sticholotis* sp. and *Cheilomenes* sp. (Coccinellidae), *Acletoxenus indicus* (Drosophilidae : Diptera) and *Chrysopa* sp. (Neuroptera) have been noticed to attack this aleyrodid. *Encarsia partenopea* exercises effective control of the whitefly in Israel, Egypt and the USA.

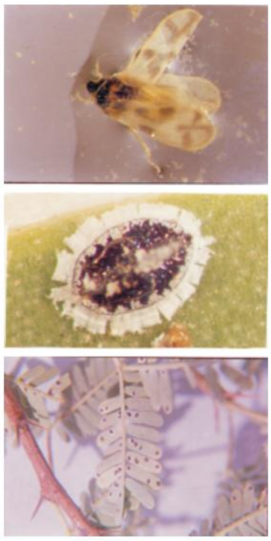
Control: Spray application of acephate 0.075% controls the pest effectively.

8. THE BABUL WHITEFLY *Acaudaleyrodes rachipora* (Fig. 57.34)

Distribution: The Babul white fly is seen in India, Pakistan, Sri Lanka, Egypt, Cyprus, Iraq, Saudi Arabia, Israel, Cameroun, Niger, Sierra Leone, Kenya, Nigeria, Sudan, etc.

Damage: This has been reported to be a serious pest of trees in forests and nurseries in the semi-arid zones of the country. The undersurface of leaflets are heavily infested causing yellowing and shedding and loss of vitality of plants. It has been reported as a serious pest of forest tree species in arid and semi-arid regions.

Life history: The adults lay suboval hexagonally sculptured eggs on the under surface of leaves with a tinge of golden yellow measuring 0.19 mm long and 0.10 mm wide. The egg is inserted into the plant tis-



▲ **Fig. 57.34** *Acaudaleyrodes rachipora: Top- Infestation on Acacia tortilis; Middle- Puparial stage with waxy covering; Bottom- Adult. (Courtesy: R. Sundararaj)* sue with a pedicel measuring 0.019 mm long. The first instar nymph crawls around for some time and gets attached to the leaf by itself and starts feeding. It does not move from that place subsequently and continues to suck the plant sap. It passes through four instars, the last instar being the puparial stage. The puparia are jet black, surrounded externally by a broad fringe of wax, broken into bands; a narrow white waxy frill extends from the margin inwards, leaving only the medial region of the dorsum exposed. The adults have hyaline wings marked with grey patches, a cross at the distal end, an irregular semicircle in the middle, and a small patch on the proximal end. *Acacia senegal* and *Prosopis juliflora* are heavily infested and most favoured by the insect.

Hosts: Abrus precatorius, Acacia anciplex, A. cavan, A. farnesiana, A. nilotica, A. senegal, A. seyal, A. tortilis, A. lebbeck, Bauhinia variegata, Carissa carandus, Cassia alata, C. auriculata, C. fistula, C. moulana, C. siamea, C. tora, Cordia gharaf, C. mixa, C. rothis, Dalbergia sissoo, Delonix elata, Dodonaea viscosa, Erythroxylon monogynum, Euphorbia hirta, E. pilulifera, Holoptelia integrifolia, Inga dulce, Lucaena leucocephala, Mimosa ?hamata, Parkinsonia aculeata, Peltaphorum ferrugineum, Prosopis juliflora, P. cineraria, Sesbania grandiflora, Securinega virosa, Tamarindus indicus, Tecomella undulata, Tephrosia purpurea, etc.

Natural enemies: The parasitoids are *Encarsia acaudaleyrodis, E. tranasvena,* and *Eretmocerus rajasthanicus* (Aphelinidae).

9. THE CARDAMOM WHITEFLY *SINGHIELLA CARDAMOMI*

The whitefly reported for the first time in 1975 from Kerala was described as *Dialeurodes cardamomi* in 1976. It is now placed in the genus *Singhiella.* The nymphs and adults suck the sap from the undersurface of leaves and cause chlorotic patches. Heavy infestation causes development of black sooty mould on honey dew excreted by the nymphs and results in poor yield and quality of capsules. It is considered to be a serious pest of cardamom in Kerala, Tamil Nadu and Karnataka. It does not transmit the Nilgiri Necrosis Virus (NNV) disease of cardamom.

A female lays 99 to 118 eggs. It can reproduce parthenogenetically, the parthenotes being females. The egg is elongate and sculptured with a short pedicel by which it is inserted into the stomata of leaf. The incubation period varies from 12 to 16 days. The nymph on hatching moves on the leaf, settles for feeding and thereafter it becomes sessile. There are three nymphal instars and fourth puparium stage. The nymphal period varies from 18 to 25 days. The adult emerges from the puparium in 10-17 days. The total life cycle takes 55-56 days during January-February and 42-45 days during March-April.

Encarsia septentrionalis and *E. dialeurodis* are parsittic and *Mallada boninensis* and *Lestodiplosis* sp. (Neuroptera) are predaceous on the nymphs. the nymphs are infected by the entomopathogenic fungus *Aschersonia placenta.*

Spray application of ethion 0.1% or acephate 0.075% or neem oil 5% is suggested.

Superfamily APHIDOIDEA1

The following three families are included in this superfamily.

Family Aphididae

Sexual forms are oviparous; parthenogenetic females are viviparous; Rs separate on fore wings, if winged.

Family Adelgidae

Both sexual and parthenogenetic females are oviparous; without separate Rs on forewings, Cu arises separately from A on forewings; wings held roof-like over abdomen at rest. Apterous parthenogenetic females covered with flocculent wax. These insects infests conifers only.

Family Phylloxeridae

Most characters are similar to that of family Adelgidae but differ in the following: Wings held flat at rest; Cu and A arise on a common stalk on forewings. Females are apterous and parthenogenetic, if possess wax, will be non-flocculent.

Family Aphididae (aphids or plant lice)

This is a large group of small soft-bodied, delicate pear-shaped insects that infest the stem or leaves of a variety of plants in large numbers and suck up the sap causing serious damage. A large number of them are significant as pests of economically important crops. The cotton aphid *Aphis gossypii*, the lab-lab or bean aphid *Aphis craccivora*, the woolly aphis *Eriosoma lanigera* the banana aphid *Pentalonia nigronervosa*, the peach leaf curl aphid *Brachycaudus helichrysi, Myzus persicae*, the corn aphid *Rhopalosiphum maidis,* the wheat aphids, *Schizaphis graminum* and *Macrosiphum miscanthi*, the ragi root aphid *Tetraneura nigriabdominalis*, the coconut aphid *Cerataphis brasiliensis* etc., are some of the common pests. Certain species of aphids are also well known vectors of virus diseases of crops. In India the aphid *Pentalonia nigronervosa* is a vector of the "Bunchy top" disease of banana and "katte disease" of cardamom (*Eletteria cardamomum*). The "chirke virus" of large cardamom (*Amomum subulatum*) is transmitted to cardamom and certain wheat varieties by the corn aphid *Rhopalosiphum maidis. Aphis craccivora, Aphis gossypii, Macrosiphoniella sanbornii* and *Myzus persicae* are vectors of the common broad bean mosaic virus.

Though the aphids primarily feed on the tender shoots, stems, and leaves a few are known to live below ground on roots. The aphid *Tetraneura nigriabdominalis* infests the roots of *Eleusine coracana* and some grasses. *Tetraneura javensis* infests roots of sugarcane. Some occur on the branches of woody trees and shrubs. Certain species infest leaves and shoots, and also the roots during different seasons. The characteristic feature of an aphid is its pear shaped structure, fairly long antennae, a pair of compound eyes, several jointed rostrum, two-segmented tarsi with paired claws, nine pairs of lateral spiracles and a pair of cornicles or “honey tubes” at the posterior end of the abdomen arising from the dorsal side of the fifth or sixth abdominal segment. Both winged and wingless forms are found, the latter being predominant in a population. In the winged forms the wings are held vertically above the body. The cornicles secrete a waxy fluid which affords protection from predaceous insects. Some species are more or less covered with waxy powder (*Hyalopterus*) or filaments or threads (*Eriosoma*), the wax being the product of dermal glands. Honeydew is excreted through the anus. It was earlier believed to be the excretion through the cornicles. Honeydew constitutes of the excess sap ingested by the aphid with additional sugars and waste materials. In some species ants are found frequently associated with them for the sake of honeydew. In certain cases definite relationship exists between the ant and the aphid, the latter being dependent on the former for care and protection. This type of relationship is noticed in the corn-field ant *Lasius alienus americanus* and the corn root aphid *Anuraphis maidiradicis*. The ants in turn get honeydew.

The life cycle of many aphids is more complicated and interesting, and the most common life cycle of a migratory aphid is as follows. The eggs laid in the autumn overwinter and give rise to apterous, viviparous, parthenogenetic females in the spring. These individuals known as fundatrices are characterised by sense organs, legs and antennae being not well developed. Winged fundatrices are met with only in *Drepanosiphon platanoidis*. The fundatrices reproduce parthenogenetically and give birth to young ones. This several generations may be produced during the summer. Only apterous females are produced in the first one or two generations. These are parthenogenetic and viviparous and they are known as fundatrigeniae. They live on the primary host itself. Winged, parthenogenetic, viviparous females or migrantes arise in the second, third or later generations. They live on primary host for some time and then fly to the secondary host. In *D. platanoidis* individuals of fundatrigeniae are absent and females are always winged. On the secondary host the individuals that develop differ markedly from the fundatrices and the migrantes. They are parthenogenetic, viviparous females known as alienicolae. Both apterous and winged forms are produced for many generations. The sexuparae or the parthenogenetic viviparous females usually develop on the secondary host and their alate forms migrate to the primary host at the end of the summer. The termination of the generations of alienicolae is marked by the sexuparae producing the sexuales. The sexuales consist of sexually reproducing males and females. The females are oviparous and with rare exceptions are apterous. They possess thickened hindtibiae and greater body length. The males are either apterous or winged, and rarely are both types produced. The oviparous females lay the eggs in the autumn and the life cycle is repeated. In the non-migratory aphids migrants and alienicolae are not recognised. Instead the apterous and winged viviparous females are known as fundatrigeniae, alatae and apterae as the case may be, and sexuparae arise from either one of them. The whole life cycle may be completed on the same plant or on individuals of the same species.

Certain physiological factors have been attributed to the polymorphism in aphids. The stage in the life cycle at which the aphids begin to feed and the rate of reproduction in species such as *Myzus persicae* are dependant on the host species, the age, and physiological condition of its leaves. Tender leaves are preferred to older leaves by aphids. With regard to polymorphism, it has been shown in *Brevicoryne brassicae* that the proportion of production of alate forms on different cabbage plants is inversely related to the protein content of the plants. Certain other workers feel that low water content in the host plant leads to production of alates. It is also believed that high temperature and continuous light directly influence the parental generation to produce apterous progeny, and low temperature and intermittent light tend to produce alate forms in *Macrosiphum solanifolii.*

1. THE CORN APHID *Rhopalosiphum maidis*

This is a pest of wheat seen in Punjab. It is confined to the unfurled leaves of the central whorl of wheat plants. They do not infest wheat grains much. Heavy infestation causes yellowish patches on leaves and leads to drying of the plants ultimately. It is a vector of the grassy-shoot and mosaic diseases in sugarcane. It also transmits chirke virus of large cardamom to cardamom and certain wheat varieties.

Viviparous, winged, and wingless forms are noticed. Winged adults are comparatively few in number in a population. Females give birth to nymphs for 10 to 25 days and live for another three days before completing the life span of 19 to 35 days. Nymphs are given birth to at one to five per day and 24 to 47 in its life span. The nymphal period is nine to ten days.

In South India it is known to infest *Sorghum vulgare, Zea mays, Panicum javanicum, Panicum antidotale, Pennisetum typhoideum, Eleusine coracana, E. aegyptiaca* and *Echinochloa colona,* apart from wheat.

It is parasitised by *Aphidius* sp.

Control: Spray 0.025% parathion or 0.025% methyl demeton.

2. THE WHEAT EAR APHID *Macrosiphum miscanthi*

In Punjab the species infests wheat. Viviparous, apterous, and alate females are seen on wheat crop. They suck the sap from leaves and tender shoots in the early stage of the crop and later get confined to the ears. Sooty mould develops on the ears and the grains become shrivelled up.

Winged adults appear in the first week of January and by mid-January apterous forms are noticed. The alate females leave their nymphs scattered all over the plant. The nymphal period is 7 to 11 days. The previviposition period is two to three days. The aphid gives birth to nymphs varying from at one to eight per day. Viviposition period is 11 to 25 days during which time it gives birth to 24 to 59 nymphs. During the last one to six days of its life it does not reproduce. Total life span is about 26 to 39 days.

The nymphal period of apterous female is 7 to 11 days. Viviposition period is 10 to 32 days and 27 to 53 nymphs are produced at one to seven nymphs per day. Post-viviposition period is one to three days. It completes about eight generations in the period ranging from mid-January to end of April.

3. THE WHEAT APHID *Schizaphis graminum*

It infests wheat in Punjab and Coimbatore. On the slightest disturbance the aphids fall off the wheat plants. Its infestation causes yellow patches and in cases of severe attack leaf becomes yellowish brown. Honeydew excretion favours sooty mould development.

Apterous and alate females are present. The nymphs are deposited on the leaf blade in a single row which then migrate to another leaf. Nymphal stage duration varies from 7 to 13 days. Viviposition and post-viviposition periods range from 19 to 26 and two to four days respectively. In its life span of 26 to 39 days a female aphid gives birth to 55 to 79 nymphs ranging from one to eight per day.

Apart from wheat, the species infests *Eleusine coracana* and *Oryza sativa.*

Cheilomenes sexmaculatus and *Coccinella* sp. (Coccinellidae: Coleoptera) are predaceous on the aphid.

4. THE PEACH LEAF CURL APHID *Brachycaudus helichrysi*

This insect has a worldwide distribution. In North India the insect occurs in Kumaon Hills, Dehradun and Himachal Pradesh, and in Nilgiris and Coimbatore in South India.

It is a major pest of peaches and also infests plum, apricot, almond, etc. It sucks the sap from buds, blossoms, petioles, tender fruits and leaves. On sprouting the leaves emerge curled, while the fruits either do not set or fall off prematurely. The infestation starts with the commencement of bud swelling and continues during and after flowering. The curling of leaves in peach caused by the aphid is often confused with the leaf curl caused by the fungus *Taphrina deformans.*

In Himachal Pradesh the eggs are laid in the axils and bases of buds in autumn. These eggs overwinter. The hatching of eggs coincides with the commencement of flow of cell sap in spring, i.e. about the middle of February at regions of higher elevations and about the end of January at regions of lower elevations. The nymphs hatch out three or four weeks before flowering and by the time flowering starts its population goes up to three to ten aphids per bud.

In Kumaon hills the aphid infests peach, plum and almond from November to May and from May to October it spends on an alternate host *Erigeron canadensis.* On both the fruit trees and *E. canadensis* reproduction is normally asexual. However, in winter one generation of sexual forms is produced which lays eggs on the primary host trees. The egg is 0.6 by 0.2 mm in size and is laid singly. The eggs overwinter and hatch in spring. The nymphs pass through three or four asexual generations. In the last generation alate forms develop which migrate to golden rod plants and pass four or five asexual generations. Later winged forms appear and migrate to fruit trees on which they lay eggs. At lower elevations no egg laying is noticed but they overwinter as adults.

The insect infests peach, apricot, plum, quince, almond, prune, *Chrysanthemum* sp., sunflower, red clover, golden rod, *Erigeron canadensis, Ageratum conyzoides, Gerbera* and *Cynoglossum furcatum.*

Pre-bloom spray of methyl demeton (0.025%) or dimethoate (0.03%) about 7 to 10 days before flowering is necessary to check damage during pre-bloom and flowering periods. A second spray may be necessary 7 to 10 days after petal fall at lower elevations to prevent re-infestation.

5. THE BANANA APHID *Pentalonia nigronervosa*

This aphid is seen in Australia, Sri Lanka and India. In India it is prevalent in Kerala, Tamil Nadu, Karnataka, Maharashtra, West Bengal and Delhi.

In India this is commonly referred to as the banana aphid. It is a well known vector of the banana bunchy top virus, cardamom mosaic ("Katte" disease), *Amomum mosaic* and "Foorkey" disease of large cardamom. The bunchy top disease of banana was first noticed at Kottayam (Kerala) in 1943. Since then it has spread to various parts. It is also found on cardamom in South India during July to February.

It infests banana plants usually in small to very large colonies consisting of alate and apterous viviparous females and nymphs. Apterous females are predominant in a population. On banana plants the aphids are seen at the base as well as the top region of the pseudostem and the leaf axils. If abundant they may be found in colonies on the exposed surface of tender leaves, mostly on the underside, on either sides of the midrib, or at the top, and within unopened leaves. Often one can notice aphid free plants near plants harbouring large colonies of the aphid.

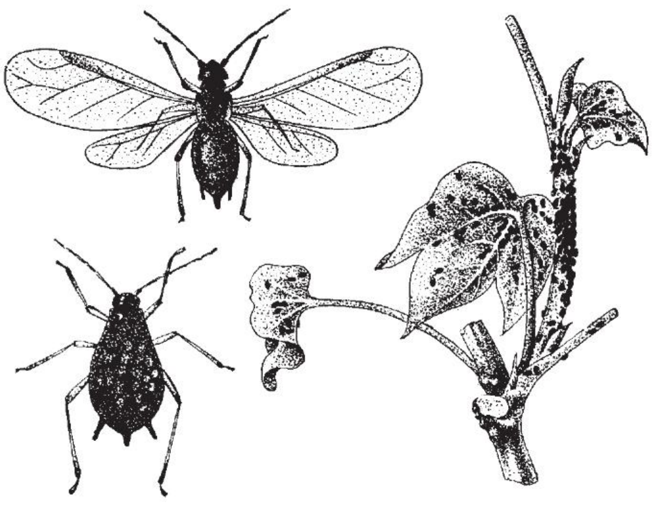
The alate and apterous females reproduce parthenogenetically and give birth to nymphs. No males are seen. A day after reaching maturity the female starts giving birth to nymphs. An aphid produces 32 to 50 nymphs during its life time at one to three nymphs per day. It passes through four instars. The nymphal period occupies eight to nine days. The longevity of an adult aphid is 23 to 27 days.

In India the aphid infests banana, *Colocasia antiquorum, Alocasia macrorrhiza,* large cardamom *(Amomum subulatum), Amomum annaecarpum, Heliconia* sp., *Caladium bicolor, Costus speciosus* and small cardamom *Eletteria cardamomum.*

Spray application of 0.05% dimethoate or methyl demeton is recommended.

6. THE COTTON APHID *Aphis gossypii* (Fig. 57.35)

The cotton aphid is of worldwide distribution. In India it occurs widely. It is a vector of the leaf-roll and 'Y' viruses in potato and the common broad bean mosaic in India.



▲ **Fig. 57.35** *Cotton aphid Aphis gossypii 1. Aphids on twigs, 2. Winged aphid, 3. Wingless aphid*

It is a polyphagous species infesting a large number of plants throughout India. However, it often inflicts appreciable damage to the cotton crop and hence is commonly known as the cotton aphid. The aphid is small, soft, yellowish green or greenish brown and is found in colonies of hundreds on the tender shoot and the undersurface of tender leaves. In cases of severe attack in the susceptible varieties, the leaves curl up, fade gradually and finally dry up. Black sooty mould develops on the honeydew excreted by the aphid which falls on the leaves, bolls, lint, etc. Apart from cotton, it is also known to be a major pest of brinjal (egg-plant), lady's finger, gingelly, chilly, guava, etc.

The females are both alate and apterous and develop parthenogenetically and viviparously. There are four instars. The nymphal period is about seven to nine days. A female gives birth to about 8 to 22 nymphs per day.

Host plants: Gossypium spp., *Solanum melongena, Abelmoschus esculentus, Capsicum annuum, Psidium guajava, Acanthospermum hispidum, Capparis stylosa, Cassia* sp., *Clerodendron serratum, Commiphora berii, Eugenia michelii, Flavaria australasia, Gynandropsis pentaphylla, Holarhena antidyssenterica, Morus alba, Ruellia prostrata, Stenosiphonium russalianum, Tagetis erecta, Vernonia cineria, Vitis vinifera, Leucas aspera, Acalypha* sp., *Amaranthus viridis, A. spinosus, Antigonum leptopus, Argemone mexicana, Bougainvillea spectabilis, Cannabis sativa, Cestrum diurnum, C. noctunum, Coccinea indica, Cordia myxa, Cyphomondra betacea, Euphorbia hirta, Eupatorium heteroclinum, Gladiolus, Hibiscus rosasinensis, Althaea rosea, lpomoea batatas, Lantana* sp., *Malvastrum coromandelianum, Medicago sativa, Petunia, Solanum nigrum, Tecoma stans, Tectona grandis, Tridax procumbens* and *Vitex negundo.*

Natural enemies: Predators–*Cheilomenes sexmaculatus, Coccinella septumpunctata, Scymnus* sp., *Coelophora bissellata, Nephus regularis, Pullus xeramphelinus, Pullus* sp. (Coccinellidae), *Chrysopa* sp. (Neuroptera), *Hemerobius* sp. (Hemirobiidae), *Syrphus confracter, Sphaerophoria javana, Ischiodon scutellaris, Syrphus balteatus, S. serarius* (Syrphidae), *Leucopis griseola, L. nigricornis* (Octhiphilidae), *Triphleps tantilus* (Anthocoridae) and *Geocoris tricolor* (Lygaeidae). Birds predaceous on the aphid are brown willow warbler (*Phylloscopus trestis*) and rufous fan-tail (*Cisticola cixsitans*).

Control: Spray application of methyl parathion 0.025%, dimethoate 0.03%, methyl demeton 0.025%, etc. is recommended. Seed treatment with thiomethoxam 70 WS at 4 g/kg seed, imidacloprid 70 WS at 5–10 g/kg seed or carbosulfan 25 DS at 50 g/kg seed has been found effective. Foliar spray application of acetamiprid 20 SP at 10–15 g a.i./ha or carbosulfan 25 EC at 400–500 g a.i./ha or thiomethoxam 25 WG at 20–50 g a.i./ha or difenthiuron 50 SC at 300–400 g a.i./ha has also been found effective.

7. THE BEAN APHID *Aphis craccivora*

This is one of the commonest aphids found throughout India infesting a variety of plants. It is a vector of broad bean mosaic disease in India. The aphid is dark brown and both winged and wingless females are seen. They reproduce parthenogenetically and viviparously. This aphid is often considered to be a serious pest on *Lablab niger, Arachis hypogaea, Glyricidia maculata, Phaseolus mungo, P. radiatus* and other pulse crops. The nymphs and adults infest the tender shoots, inflorescence and tender fruits or pods in large numbers and suck the sap. In the early stages of the development of the plant, the tender shoots will dry up due to the aphid feeding on the cell sap. Flower buds, flowers, and tender pods will fall off prematurely. Tender pods may shrivel up and dry in due course.

Host plants: Alysicarpus rugosus, Geisekia pharmaceioides, Glyricidia maculata, Amaranthus sp., *Moringa oleifera, Gynandropsis pentaphylla, Mirabilis jalapa, Phyllanthus amarus, Arachis hypogaea, Kochia* sp., *Medicago sativa, Phaseolus mungo, P. radiatus, P. trilobus, Sesbania grandiflora, S. speciosa, S. aegyptiaca, S. aculeata, Tribulus terrestris, Vigna ungiculata (cowpea), Cyamopsis tetragonoloba, Lablab niger, Indigofera trita, I. nigra, I. enneaphylla, Antigonon leptopus, Boerhaavia diffusa, Crotalaria juncea, Tephrosia purpurea* and *T. trita.*

The coccinellid *cheilomenes sexmaculatus* is predaceous on the aphid.

Control: Control measures as for cotton aphid. Menazon 0.05% spray has also given effective control of the aphid.

8. THE RAGI ROOT APHID *Tetraneura nigriabdominalis*

It is seen in Africa, South-East Asia to New Guinea, Japan, Taiwan, Southern U.S.A. and Australia.

The aphid is minute, pink and globular. They are found as colonies, feeding on the freshly formed roots of ragi plants. The black ant *Camponotus compressus* is associated with on the aphid for its honeydew. The external evidence of the infestation of the insect is the gradual weathering away of badly infested plants and the presence of black ants visiting the roots. When such plants are pulled out colonies of the insect can be seen attached to the roots. The infestation prevails up to the flowering stage. In Coimbatore irrigated ragi is affected seriously during May–July.

The insect develops by parthenogenetic viviparous reproduction throughout the year on several grasses. The alate forms that are produced after two or three generations of apterous forms are responsible for the dispersal of the aphid. They are dispersed by wind and subsequently nymphs are produced on the leaves. These find their way to the roots near the soil and the black ants excavate the soil and provide facilities for the aphid to multiply.

Host plants: Andropogon halli, Cymbopogon martini, Cenchrus ciliaris, C. setigerus, Chinoachne semetteres, Dicanthium annulatum, lseilima laxum, Panicum maximum, Pennisetum cenchroides, P. purpureum, Schima nervosum, Sorghum vulgare, S. halepense, Digitaria sp., *Eleusine coracana, E. aegyptica* and *Oryza sativa.*

Control: Drenching the soil with dimethoate 0.05% at 1800 litres/ha may be effective.

Family Pemphigidae

9. THE WOOLLY APHIS *Eriosoma lanigera*

The woolly aphis, a serious pest of apples, is of worldwide distribution. It is a native of America. In Punjab it was first noticed in 1909 in the Simla district on young apple plants which had been imported from England. It is now a major pest in the hill districts of Uttar Pradesh. It also infests apple plants in Nilgiris, Tamil Nadu. It caused serious infestation of apple on the Nilgiris in 1940 and was finally checked by the introduction of its specific parasite *Aphelinus mali* from Punjab.

It is found on apple trees throughout the year sucking sap from branches, twigs and occasionally from leaves and calyx. When it attacks the aerial portions the entire stem and most of the branches get covered with galls, the condition affecting the vitality of the tree adversely. The attacked twigs may die. Young nursery plants usually succumb to the attack of the woolly aphis. When roots are infested galls are produced and the vigour of the trees is impaired to a greater extent. The fruits from a heavily infested tree is of poor quality, being undersized, malformed and insipid in taste.

The presence of a white cottony mass covering the aerial parts of the attacked plants indicates the infestation by woolly aphis. The aphid which remains concealed underneath the white cottony mass is purplish and 1.0 by 0.05 mm in size.

Reproduction is both sexual and asexual. Generally it develops parthenogenetically and in a year there are several generations. The winter from mid-December to mid-Februrary, is the non-reproductive period. Overcowintering occurs during the first and second instar nymphal stage. Apterous forms are present throughout the year. Alate forms are seen from July to October in Kumaon only. Alate forms disperse by flight and give rise to apterous forms by sexual reproduction.

Migration of aphid from aerial part to base of trunk just below the soil takes place in the winter and return migration takes place during the summer. Upward and downward movements of colonies are noticed throughout the year in Uttar Pradesh, the movement being very reduced during winter. In Himachal Pradesh (Kulu Valley) aerial forms migrate to the roots during mid-winter but partial migration from roots to stems is noticed only during May.

Males are rarely found in the aphids occurring in Kashmir and sexual reproduction is also noticed. Further, root forms of the aphid are also not generally seen in Kashmir.

Natural enemies: Syrphus balteatus, S. confracter (Syrphidae), *Adalia bipunctata* and *Coccinella septempunctata, Coleophora sauzeti, Cheilomenes bijugans infernalis, Ballia eucharis* (Coccinellidae), *Coniocompsa indica* (Coniopterygidae, Neuroptera) and *Ancylopteryx punctata* (Chrysopidae: Neuroptera) are predaceous on the woolly aphis. However, the pest is effectively controlled by the parasite *Aphelinus mali.*

Control: Root infestation may be controlled by application of the fumigant paradichlorobenzene at 30 to 110 gm per tree in a 15 cm deep trench around the tree about two metres away from the base of the affected tree. Aerial infestation may be controlled by spraying with diazinon 0.05%, ethyl parathion 0.03%, menazon 0.05%, carbaryl 0.05%, endosulfan 0.035%, dichlorvos 0.05%, dimethoate 0.035% or formothion 0.037%. Resistant stocks and *Pyrus baccata* are used in Uttar Pradesh.

Family Callaphididae

10. THE WALNUT APHID *Callaphis juglandis*

Walnut (*Juglans regia)* occupies around 33000 ha in Jammu & Kashmir producing 21,500 MT of fruits annually. Of the two species viz. *Callaphis juglandis* and *Chromaphis juglandicola,* the former is important.

The dusky veined aphid *Callaphis juglandis* infests the upper surface of walnut leaves along the mid veins. There are 20–22 aphids per ten leaves and its infestation causes premature leaf drop, reduced nut size and yield, apart from production of large amount of honeydew which favours growth of sooty mould on leaf and husk of the developing nuts. It overwinters in the egg stage for about seven months. The eggs laid in August hatch in third week of April next year. Thereafter it completes ten generations from April to August. First six generations pass through three nymphal instars of 2.5 to 4.8 days with a development period of 11.0 to 17.5 days, while the last four generations passes through only two nymphal instars ranging between 2.8 and 3.4 days, the development period being 9.2 to 10.1 days. Apterous forms appear after 10^{th} generation. Light yellowish eggs are laid singly on the axil of the buds and an egg measures 0.24 mm long. An adult lays on an average 30 eggs. Adults survive for seven to nine days.

Family Lachnidae

THE GIANT WILLOW APHID *Tuberolachnus salignus*

This aphid contributes to the formation of nutritious honey. Honey dew excreted by an individual of the different nymphal instars of the giant willow aphid varies from 2.27 to 27.38 mg / day. The bark feeding aphids excrete voluminous honeydew during July – September. It crystallises as a sugary deposit on and below the willow trees, growing in the dry temperate zone of the Himachal Pradesh. According to the intensity of infestation, 2 to 5 kg of honeydew per tree can be collected. *Dungsee,* a sweet product prepared from it, is a rich source of carbohydrate (67.98% total sugars), protein (10.15%) and minerals (1.6%). In Spiti Valley and its adjoining areas in H.P., the tribals are known to relish sugary substance *Dungsee.*

Family Chaitophoridae

This family is represented by genera like *Chaitophorus, Periphyllus, Sipha,* etc.

Family Thelaxidae

This family includes genera like *Hormaphis, Anoecia, Mindarus,* etc.

Family Adelgidae (pine and spruce aphids)

Adelgids feed only on conifers and live on needles, twigs or in galls. Life history of most species is spent on two different conifers, forming galls only on the primary host. The females are all oviparous. Antennae are five-segmented in alate forms, four-segmented in sexual forms and three-segmented in the apterous parthenogenetically reproducing females. Body covered with flocculent waxy threads.

Family Phylloxeridae (phylloxerans)

Only a few species are represented in this family. The grape phylloxera *Phylloxera vitifoliae* is a well known destructive pest of grape. It is a native of middle and eastern United States. The insect causes formation of galls on leaves and gall-like swellings on the roots. The European grapes or *vinifera* varieties are highly susceptible to the pest. The insect was introduced in France in 1860 and at about the same time it was also noticed in California. The life history of the phylloxeran is much more complicated than that of the aphid. However, it will be of interest to know that parthenogenetic females and sexually perfect females of *Phylloxera* sp. lay eggs.

Superfamily COCCOIDEA (Scale Insects and Mealy Bugs)

The scale insects and mealy bugs are minute, inconspicuous and highly specialised insects. The females are apterous and usually apodous and sessile. Segmentation of the body is obscure. The antennae are often atrophied but, if present, may even be 11-segmented. Tarsi one-segmented with a single claw, if present. Rostrum is short. In most cases the insects have waxy or powdery coatings, or may look like a scale or gall. The males are unique in possessing 10 to 25-segmented antennae and a pair of forewings, the hindwings being reduced to haltere-like structure. Rarely the males are apterous as in *Kerria lacca* and *Saccharicoccus sacchari.* The mouthparts are atrophied and adult males do not feed. The abdomen ends in a stylet like process. The terms mealy bugs and scales commonly used refer to only the female forms which are encountered most frequently than the adult males.

The food habits of these insects are variable and they infest the leaves, stems and fruits of a wide variety of plants. Some even infest the roots of plants. Many species are economically important as pests of crops. The San Jose scale *Quadraspidiotus perniciosus* is a pest of fruit trees. The cottony cushion scale or fluted scale *Icerya purchasi* is a serious pest of citrus and other fruit trees. The green bug *Coccus viridis* on coffee, the diaspidine scale *Melanaspis glomerata* on sugarcane, the scale *Aspidiotus destructor* on coconut, *Saissetia* sp. on a number of crops and *Lepidosaphes cornutus* on betelvine are some important scale insect pests of crops. Among mealy bugs, *Brevennia rehi* on rice, *Kiritshenkella sacchari* on sugarcane, *Coccidohystrix insolitus* on brinjal and *Ferrisia virgata* on a wide variety of plants and trees are some important pests.

Geococcus coffeae infests tender roots and tubers of sweet potato in Coimbatore and *G. citrinus* infests roots of Piper betel in Tamil Nadu. *Rhizoecus* sp. has been reported to infest roots of coconut in Kerala. A few mealy bugs such as *Dysmicoccus brevipes, Ferrisia virgata, Planococcus citri* and *Pseudococcus comstocki* are known as vectors of the cacao mosaic disease in Trinidad. *Planococcus citri* and *P. lilacinus* are vectors of cacao swollen shoot virus in Sri Lanka.

Apart from being injurious to crop plants and trees, a few are known to be highly beneficial and useful to mankind. The prickly pear cochineal *Dactylopius opuntiae* had been successfully used in the eradication of the weed *Opuntia dillenii* in India. A dye can be extracted from the wild cochineal *Dactylopius indicus* on *Opuntia vulgaris* in South India. Similarly dye is also extracted from the bodies of the females of *Dactylopius coccus*, a native of Mexico. The shellac of commercial importance is obtained from stick-lac. This is a secretion obtained from the lac insect *Kerria lacca* in India.

Coccids reproduce bisexually and in some cases parthenogenetically. They are mostly oviparous or may be ovoviviparous or viviparous. Functional hermaphroditism has been noticed in *Icerya purchasi.* In oviparous forms the eggs may be found enclosed in an ovisac covered with waxen threads (*Pseudococcus* sp.) or beneath the scale-like covering of the female as in diaspidine scales, or between wax plates secreted from the end of the abdomen as in *Orthezia*, or beneath the body of the females as in *Eulecanium.* The first instar nymphs, by which the dispersal of the species is ensured, are mobile with functional legs and they are commonly called as crawlers. The subsequent nymphal instars and adult females become stationary and fix themselves to the host plant by inserting their stylets and suck the sap. One or more of such subsequent nymphal instars may be apodous excepting in Pseudococcidae wherein the nymphs always possess legs. Males pass through one additional instar stage than the females. A few coccids exude honeydew, and ants are attracted to this exudation. Ants are noticed to be responsible for greater dispersal of the coccid.

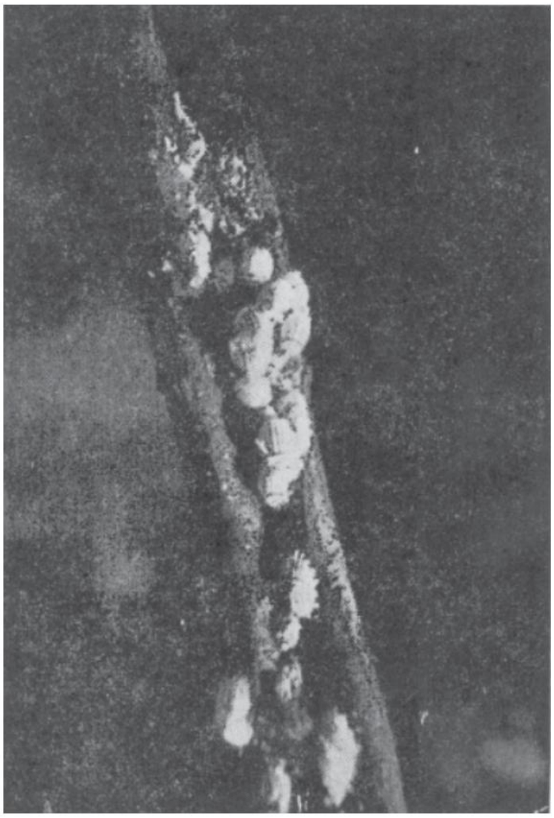
The following are some important families of Coccoidea.

Family Margarodidae

Characterised by females having distinct segmented body, often covered by waxy secretion. The forms belonging to the genus *Margarodes* are subterranean in habit and are referred to as "Ground Pearls". *Margarodes niger* and *M. papillosa* are found in soil under grass roots in South India. In *Monophlebus* adult females have a mealy covering and those of *Icerya* have a woolly covering. *Walkeriana senex* infests *Punica granatum* in Wynaad and *Barberis lycium* at Ootacamund. *Drosicha mangiferae* is a pest of citrus, mango, etc. in Northern India.

1. THE COTTONY CUSHION SCALE OR FLUTED SCALE *Icerya purchasi* (Fig. 57.36)

Icerya purchasi, first discovered in New Zealand, was described by Maskell in 1878. Since then this has been reported from many countries all over the world as a well known pest of citrus, apple, peach, fig, walnut, apricot, pomegranate, grape, rose, almond, potato, etc. It was known to be a serious pest of citrus in California and its control was possible only by the introduction of its natural enemy *Rodolia cardinalis.* The insect was first noticed in India during the spring of 1928. In the Nilgiris it was found to breed on more than 100 host plants but the only crop of commercial importance which had suffered most was *Acacia decurrens.* The insect was brought under control by the introduction of the predatory coccinellid *R. cardinalis* from California in 1929 and from Egypt in 1930. Again in 1942 the outbreak of the insect was noticed on the Kodaikanal Hills. Control was achieved by systematic release of the above natural enemy. In addition to biological control, move-



▲ **Fig. 57.36** *Icerya purchasi on citrus (courtesy: W. Buttiker, Ciba-Geigy, Switzerland)* ment of wattle from the Nilgiris and Kodaikanal was quarantined for which special quarantine stations were maintained for a few years. The pest is now kept under natural check in the above places by *R. cardinalis*.

2. THE MANGO MEALY BUG *Drosicha mangiferae*

It is a serious pest in Northern India, especially on mango and citrus.

The nymphs and adults suck the sap from tender stem, leaves and fruits. In cases of severe infestation the tree shows sickly appearance. In citrus the growth is impaired. Leaves and flowers are shed resulting in poor setting and premature fruit fall. The honeydew excreted by the insect favours development of sooty mould which also affects normal photosynthetic activity. Older fruits do not develop properly.

The winged male soon after emergence mates with the apterous female. Though the female mates only once the male fertilises more than one female. The mated female descends the tree and reaches the soil for oviposition. The pre-oviposition, oviposition and post-oviposition periods vary from 18 to 27, 17 to 26 and up to 8 days respectively in the females seen on citrus plants in Madhya Pradesh. The fecundity varies from 56 to 580 eggs. The eggs are laid inside cottony white ovisacs during April to beginning of June at a depth of 50 to 175 mm in loose soil near or away from the base of the trees. If the soil is somewhat hard they may be laid in the cracks of the soil and bark. The nymphs hatch out from the eggs during September-February, but mostly during November. The incubation period varies from 98 to 185 days which is attributed to differences in soil temperature and humidity. The nymphs start ascending the trees from October-November. They congregate in the axils of twigs and cracks of the bark in clusters of 17 to 283. Females have four nymphal instars and males three. The total developmental period from egg to adult on citrus varies from 160 to 304 days in female and 165 to 290 days in male. The pre-pupal and pupal periods of the male ranges from two to five and 6 to 13 days respectively. The black ant *Camponotus compressus* associates with the bug for its honeydew excretion. There is only one generation in a year.

Host plants: Mango, citrus and over 60 other plants.

Natural enemies: *Coccinella septumpunctata, C. undecimpunctata, Cheilomenes sexmaculatus, Rodolia fumida, Aulis vestita* (Coccinellidae) and larvae of *Chrysopa scelestis* and birds are predaceous on the insect. An entomogenous fungus *Aspergillus parasiticus* is parasitic on it. A mite *Bochartia* sp. is an ectoparasite on the adults and nymphs.

Control: Application of quinalphos 1.5% dust or methyl parathion 2% dust around the bases of trees, and spraying of methyl parathion 0.05% or malathion 0.05% for controlling early instar nymphs would be useful.

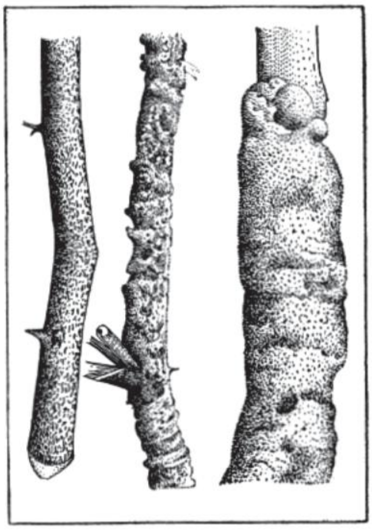
Family Ortheziidae

The family is native to America and the Palaearctic region. Segmentation of the body of females is distinct and covered with white waxy plates. Antennae, simple eyes and legs are prominent.

The Lantana bug *Orthezia insignis* is a well known insect having a wide distribution in many parts of the world. The adult female has white waxy laminae at the extremity of the body and the egg sac is situated between these waxen plates. Short waxy processes at the sides and a double row of similar processes along the back are present. The insect is olive green in colour with well developed legs and antennae. The lantana which is a serious weed on the hills is kept under check by this bug to a great extent. However, as it attacks other useful plants such as *Coleus*, it cannot be considered to be exclusively useful and at times may become harmful.

Family *Kerriidae* (lac insects)

This family is mostly confined to tropics and subtropics. The Indian lac insect *Kerria lacca* (Fig. 57.37) has a wide distribution in India, and the resinous secretion of the females provides the stick-lac, which is of great commercial importance. The apterous females are highly degenerate with vestigial antennae. The body is irregularly globose and enclosed in a resinous mass secreted by the lac-resin glands distributed all over the dermis except near the two bran-chial pores and the anal tubercular region. The encrustation covers the twigs of host trees to a thickness of 6 to 12 mm. The species of *Kerria* other than *K. lacca* that occur in India are *K. albizziae, K. ebrachiata, K. fici* and *K. indicola.*



▲ **Fig. 57.37** *Lac on Ber (T. B. Fletcher, 1914)*

Family Pseudococcidae (mealy bugs)

Mealy bugs are characterised by their bodies being covered with mealy or waxy secretions. They are elongate to oval in shape with distinct segmentation. Antennae are present and legs are well developed. Eggs are laid by some species and others are viviparous or ovoviviparous. If oviparous the eggs may be laid in loose cottony wax. This family includes a number of economically important species. The rice mealy bug *Brevennia rehi*, the sugarcane mealy bugs *Kiritshenkella sacchari*, *Saccharicoccus sacchari* and *Phenacoccus saccharifolii*, the brinjal mealy bug *Coccidohystrix insolitus*, the white-tailed mealy bug *Ferrisia virgata*, the mango mealy bug *Rastrococcus iceryoides, Planococcus citri, Planococcus lilacinus* on coffee and the pineapple mealy bug *Dysmicoccus brevipes* are some important pest species in India.

1. THE RICE MEALY BUG *Brevennia rehi*

Distribution: India, Nepal, Pakistan, Sri Lanka, Myanmar, Malaysia, Thailand, Philippines and Cuba.

Damage: The mealy bugs remain concealed within the leaf sheath and suck the sap. Heavy loss of sap results in loss of vigour and yellowing of leaves. The infestation is characterised by round or oval sunken patches in the midst of a normal crop. The plants in the affected patches die in course of time and those that survive seldom put forth normal panicles. The few panicles that may emerge are distorted and chaffy. This insect is responsible for the malady known as "Soorai" on rice in Tamil Nadu.

Life history: The elongate eggs are laid in a chain. Each egg measures about 0.3 mm long. A female lays 58 to over 300 eggs. The crawlers hatch out from the eggs in about 3 to 24 hours. The crawlers are initially white and later the nymphs become pinkish. The nymphs remain covered with waxen threads inside the leaf sheath and suck the sap. Nymphal period ranges from 17 to 37 days. Adult female is wingless and is covered with a white wax. The adult male is pale yellowish and possesses a pair of wings. Dispersal is by the crawlers moving about to new plants or by being carried in irrigation water to fresh water.

Host plants: Oryza sativa, Eleusine coracana, E. aegyptiaca, Andropogon annulatus, Apluda varia, Leptochloa polystachya, Ischaemum ciliare, Paspalum scrobiculatum, Setaria glauca, Cynodon dactylon, Cyperus rotundus, Eragrostis interrupta, Eriochloa polystachya, Isachne australis, Iscilema laxum, Leptochloa chinensis, Cymbopogon caesius, Digitaria sanguinalis, Chloris barbata, Panicum colonum, P. repens, P. javanum, P. prostratum, Fimbristylis argentea, F. miliacea, F. tenera, Tuncellus pygmaeus, Saccharum spontaneum and *Sorghum vulgare.*

Natural enemies: In India the following natural enemies have been reported. Predators–*Scymnus* sp., *Gitona perspicax*, *Leucopis luteicornis*, *Mepachymerus ensifer* and *Amatrichus pygmaeus* (Chloropidae) and ants. Parasites–*Doliphoceras* sp. and *Xanthoencyrtus* sp. (Encyrtidae).

Control: 1. Removal of affected plants in the early stage of attack and spraying a suitable insecticide. 2. As it breeds on a variety of grasses, the grasses along the field bunds should be removed and destroyed while trimming the bunds. 3. Spraying parathion 0.05% or dimethoate 0.03% may be useful.

2. THE SUGARCANE MEALY BUG *Kiritshenkella sacchari*

This species prefers either the root or the underground parts of the stem and are only occasionally found in the nodal regions of sugarcane. The mealy bug is pinkish, 2.5 to 4 mm long and possesses six-segmented hairy antennae. No ovisac is present in this species and the eggs are laid in a chain and lie underneath the abdomen. The incubation period is about 14 hours. In Bihar, the total life cycle is completed in about 18.6 days during April. So far no male has been observed. It infests *Saccharum officinarum, S. arundinaceum* and *Imperata arundinacea.*

3. THE SUGARCANE SPINDLE MEALY BUG *Phenacoccus saccharifolii*

This species seems to be predominantly confined to the leaf blade and upper part of leaf-sheaths of sugarcane. Adult female is yellowish and measures about 4 mm long. Antennae are 8-segmented. The eggs are laid within an elongated ovisac protruding behind the body. The incubation period varies from five to six days. In Bihar the total life cycle occupies about 25 to 28 days during August. Reproduction is sexual. It also infests *Saccharum arundinaceum* and *Sorghum halepense.* It is a vector of spike disease of sugarcane in India.

4. THE SUGARCANE LEAF-SHEATH MEALY BUG *Saccharicoccus sacchari*

This insect mainly attacks the nodes of the stem beneath the leaf sheath of sugarcane. The eggs are laid in concealed ovisac (i.e. never in a definite ovisac) underneath the abdomen. Incubation period is less than eight hours. The insect is also capable of reproducing ovo-viviparously. Adult female is pink, measures about 5 mm long and possesses seven-segmented antennae. The total life cycle is completed in about 20 days during August in Bihar. Apterous males have been reported from Coimbatore. It is also known to infest *Sorghum vulgare.*

5. THE MANGO MEALY BUG *Rastrococcus iceryoides*

This insect is found distributed throughout India and is known to be a pest of mangoes in the North.

The nymphs and adult females suck the sap from leaves, tender terminal shoots, inflorescence and fruits. The leaves are infested by the early instar nymphs. Honeydew excreted by the mealy bug favours development of sooty mould. Infestation causes shedding of flowers and thus fruit setting is affected considerably. The red tree ant *Oecophylla smaragdina* is found in association with this mealy bug. The insect is abundant during April–June and thereafter declines. By October it is not generally observed. In Jabalpur it passes through 6 to 9 generations in a year and overwinters as adult female.

Life history: Male copulates with the female soon after emergence. The pre-oviposition period ranges from seven to nine days. It lays about 400 to 630 eggs. The egg is oval, pale yellow and measures 0.24 × 0.15 mm. The eggs are laid in waxy ovisacs on shoots and inflorescences. The incubation period is six to nine days. Females moult three times and males four times and show complete metamorphosis. Nymphal period in male is about 18 days in May and 26 days in August whereas in female it is 20 and 31 days respectively. Longevity of adult male is one to two days whereas that of mated and non-mated females respectively being 13 to 23 and up to 80 days.

Host plants: *Mangifera indica, Boswellia* sp., *Capparis horrida, Odina wodier, Hibiscus rosasinensis, Gossypium* sp., *Lablab niger, Citrus, Ficus indicus, Plectronia parviflora, Enterolobium saman* (rain tree), *Murraya koenigii*, etc.

Natural enemies: *Tetrastichus* sp. (Eulophidae) is parasitic. The larvae of a lycaenid butterfly *Spalgius epius* is predaceous on the mealy bug.

6. THE BRINJAL MEALY BUG *Coccidohystrix insolitus*

Distribution: It is one of the important pests of brinjal (*Solanum melongena*) in India. The insect is found distributed in India and Sri Lanka.

Damage: The nymphs and adult females remain in large numbers on the undersurface of leaves and suck the sap causing yellowing, wilting and drying of plants. The honeydew excreted by the bugs favours development of sooty mould. The insect is abundant during June–August.

Life history: The male soon after emergence copulates with the female, mating lasts about 2 to 3 minutes. The pre-oviposition period ranges from 2 to 12 days. No parthenogenesis has been noticed. The fertilised female lays the eggs in an ovisac which protrudes behind its body. The oviposition and post-oviposition periods range from four to eight and 1 to 12 days respectively. A female may lay 98 to 209 eggs, the average being 171 eggs. The incubation period is three to eight days. The females pass through incomplete metamorphosis and moult three times and attain maturity in 11 to 19 days. The males pass through complete metamorphosis, moult four times and the total duration of post-embryonic development takes about 13 to 18 days. After the first moult a cocoon is formed inside which the nymph completes the rest of its development.

In association with the mealy bug on brinjal two ants *Camponotus compressus* and *Paratrechina longicornis* have been noticed.

Host plants: Achyranthes aspera, Abutilon indicum, Capsicum annuum, Euphorbia pulcherima, Lycopersicon esculentum, Physalis peruviana, Solanum hispidum and S. melongena.

Natural enemies: Insects parasitic on this mealy bug are: *Coccophagus manii, Promuscidea unfaciativentris* (Aphelinidae), *Doliphoceras tachikawai, Leptomastix nigricoxalis, Neocharitopus orientalis, Prochiloneuroides albofuniculatus, Prochiloneurus insolitus* (Encyrtidae), *Chartocerus hyalipennis, C. kerrichi* and *C. kurdjumovi* (Thysanidae). The coccinellids *Hyperaspis maindronia* and *Nephus regularis* are predaceous.

Control: Spraying systemic insecticides may afford some relief.

7. THE WHITE-TAILED MEALY BUG *Ferrisia virgata*

Distribution: It is a widely distributed species in tropical and subtropical countries, causing serious damage to a large number of host plants of economic importance.

Damage: The insect is found as a cluster upon the terminal shoots, leaves and fruits and sucks the sap which results in yellowing, withering and drying of plants, or shedding of fruits, etc. It is generally abundant during August-November. It has the usual habit of encircling itself by secreting thin glassy threads of wax specially when its population is less.

Life history: The female bug is apterous with two long prominent waxy filaments at the posterior end and a number of waxy hairs over the body covered with waxy powder. In the posterior end of the body the dorsum has a prominent blackish patch. Its size is 4.3×2.1 mm., and is very active and mobile throughout its life. Reproduction takes place both sexually and parthenogenetically, the latter being more common. Mating takes place only once and lasts for about 12 to 23 minutes. The female lays the eggs in groups which lie under its body. Fecundity ranges from 109 to 185 during an oviposition period of 20 to 29 days. The incubation period is about three to four hours. Female and male nymphs moult three and four times respectively and the development period respectively varied from 26 to 47 and 31 to 57 days. Longevity of female is 36 to 53 days and that of male only 1 to 3 days.

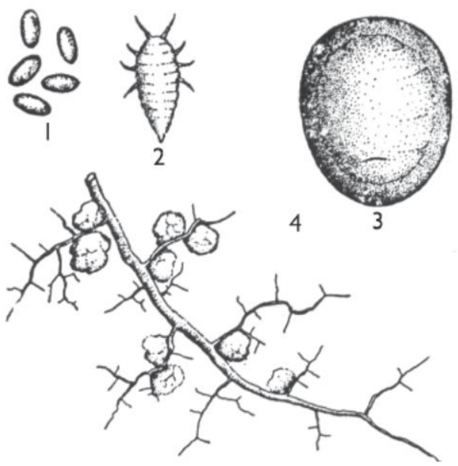
Host plants: Acalypha indica, A. wilkesiana, Achyranthes aspera, Abelmoschus esculentus, Anacardium occidentale, Amaranthus sp., *Anona squamosa, Artocarpus heterophyllus, Asparagus* sp., *Begonia* sp., *Brachycome* sp, *Coccinia indica, C. cordifolia, Cactus* sp., *Casuarina equisetifolia, Castilloa elastica, Colocasia* sp., *Croton latifolium, C. tortuosum, Coleus* sp., *Celosia cristata, Citrus* sp., *Colliandra* sp., *Corchorus olitorius, Corallocarpus spigaea, Daedalacanthus nervosus, Lablab niger, Dodonaea viscosa, Dracaena* sp., *Eranthemum* sp., *Ficus bengalensis, Gossypium* sp., *Gerbera* sp., *Hibiscus chinensis, Ipomoea palmata, I.hederacea, Lantana* sp., *Lawsonia alba, Lilium* sp., *Lycopersicon esculentum, Morus* sp., *Musa sapientum, Mimusops elengi, Nicotiana tabacum, Psidium guajava, Phyllanthus emblica, Piper nigrum, P. betel, Punica granatum, Portulaca grandiflora, Sagittaria* sp., *Solanum melongena, S. nigrum, Sesbania speciosa, S. aegyptiaca, S. bispinosa, Tagetes erecta, Talinum* sp.,*Thunbergia* sp., *Trichosanthes dioecta, Vitis vinifera* and *Viola odorata.*

Natural enemies: The lygaeid bug *Geocoris tricolor* and the coccinellids *Nephus regularis* and *Pullus coccidivora* are predaceous on the mealy bug. An entomogenous fungus *Aspergillus parasiticus* is parasitic on the mealy bug.

Control: Parathion 0.05% and dimethoate 0.03% sprays are effective against the pest.

8. THE COCONUT ROOT MEALY BUG *Rhizoecus* sp. (Fig. 57.38)

This mealy bug was first noticed to infest the roots of coconut in sandy tracts of Thiruvananthapuram in the year 1977. The full grown mealy bug is cream coloured, subglobular and measures 2.4 mm long and 1.9 mm broad. Each insect is enclosed within a loose jacket of pure white cottony felt. Mealy bugs in groups feed on thin fibrous roots at



▲ **Fig. 57.38** *Life stages of Rhizoecus sp. 1 – Eggs, 2 – Crawler, 3 – Adult female, 4 – Root showing felt growth of the mealy bug (after M. R. G. K. Nair, A. Visalakshi and George Koshy, Entomon, 1980)* the junctions with side roots. Eggs are laid in continuous chains through the genital pore which emerge out of the felt covering and subsequently get detached and get distributed among the sand particles around the roots. The female lays smooth, white, oval eggs measuring 0.48 mm long and 0.24 mm broad. The number of eggs laid varies from 67 to 82. The crawler is white and measures 0.48 mm long and 0.21 mm broad. The infested roots become brownish and dries up. Young plants show yellowing and loss of vigour.

Family Dactylopiidae (cochineal insects)

The adult females resemble mealy bugs and are reddish in colour. The elongate to oval and distinctly segmented body is covered with white waxy plates. This family includes the cochineal insect *Dactylopius opuntiae* and *D. ceylonicus* which were useful in the eradication of the prickly pears in India and Australia. Pigments are extracted from the dried bodies of cochineal insects like *Dactylopius indicus* and *D. coccus.*

Family Coccidae (soft scales, wax scales, tortoise scales)

The females are flat and elongate-oval with the integument smooth or covered with wax. They may possess legs or legs may be wanting. Antennae may be wanting or much reduced if present. The males may be alate or apterous.

The family includes a number of destructive species. *Chloropulvinaria psidii* is one of the commonest scale insects in South India. It infests guava, mango, *Morinda*, tea, coffee, *Eugenia calophyllipholia, Ficus retusa, Carissa, Nuxvomica,* etc. *Pulvinaria maxima* is very common on neem, cotton, etc. The species of *Ceroplastes* are commonly referred to as wax scales. *Ceroplastes rubens* is an important pest of mango, citrus, jack, etc. in India. *Ceroplastodes cajani* is a common major pest on *Ocimum, Cajanus cajan, Lablab niger, Zizyphus* sp., *Tephrosia purpurea* and *Coleus* sp.; *Saissetia hemisphaerica* known as brown scale is a pest of coffee, citrus, *Achras zapota*, guava, *Hibiscus rosasinensis*, *Coccinia indica*, *Sauropus androgynous, Abelmoschus esculentus*, mango, ferns, *Tabernaemontana* sp., *Trichosanthes anguina*, etc. The black scale *Parasaissetia nigra* infests cotton, crotons, *Abelmoschus esculentus*, sandalwood, nutmeg, coffee, etc. *Coccus viridis* is a major pest of coffee in India.

THE COFFEE GREEN SCALE *Coccus viridis*

Distribution: The insect is found in India and in all coffee growing regions of the world.

Damage: This is one of the major pests of *arabica* and *robusta* coffee in South India. The bugs infest the undersurface of leaves and are found more frequently along the midrib and veins. They also cover the petiole, tender shoots and berries. In cases of severe attack, the tender shoots droop and defoliation sets in due to loss of the cell sap. The honeydew excretion of the bugs favour development of sooty mould. The plants become stunted and yield of berries is reduced considerably.

Life history: The scale is flat, pale green or yellowish green, ovate, slightly convex and measures about 3 mm long. The insect reproduces ovo-viviparously and a female gives birth to 300 to 500 young ones which remain for a short time under the body of the female and then move about actively. They attach themselves to the leaves, tender shoots or tender berries and feed on the sap. They attain maturity in four to six weeks. The adult female lives for about two to five months. The broods often overlap. The ants *Oecophylla smaragdina, Cremastogaster* sp. and *Camponotus* sp. are found associated with the scale. The infestation starts in February-March and is severe during May.

Host plants: Coffee, *Citrus* sp., tea (*Camellia sinenis*), *Ficus* sp., *Aegle marmelos, Carissa* sp., guava, *Plumeria acutifolia, Canthium dicoccum* and *Alstonia scholaris.*

Natural enemies: The entomogenous fungi *Empusa lecanii* (black fungus), *Cephalosporium lecanii* (white fungus), *Hypocrylla olivaceae* and *Entomophthora freshnii* exercise appreciable natural control of the bug under conditions of high humidity and warm temperature. *Coccophagus bogoriensis, C. lycimnia* (Eulophidae) and *Cheiloneuromyai javensis* (Encyrtidae) are parasitic. The coccinellid beetles *Chilocorus circumdatus, Cryptolaemus montrouzieri* and *Rodolia* sp. are predaceous on the scale.

Control: Spraying parathion 0.05%, diazinon 0.04%, fenitrothion 0.05%, malathion 0.05%,, dimethoate 0.03% may be effective.

Family Aclerdidae

This family includes the species of the genus *Aclerda. Aclerda japonica* infests sugarcane in India.

Family Asterolecaniidae (pit scales)

The adult females are small, elongate to oval and the body is covered by a tough waxy film or embedded in a waxy mass. *Lecaniodiaspis azadirachtae* lives in a shallow pit on the mid-vein of the leaflet of *Azadirachta indica* seen in Coimbatore. *Anomalococcus indicus* infests *Acacia arabica. Asterolecanium robustum* is found on bamboo. *Cerococcus hibisci* has a thick covering of pale yellow test and is known to infest *Coffea arabica, Gossypium* sp.. *Hibiscus rosasinensis*, *H. mutabilis*, etc.

Family Diaspididae (armoured scales)

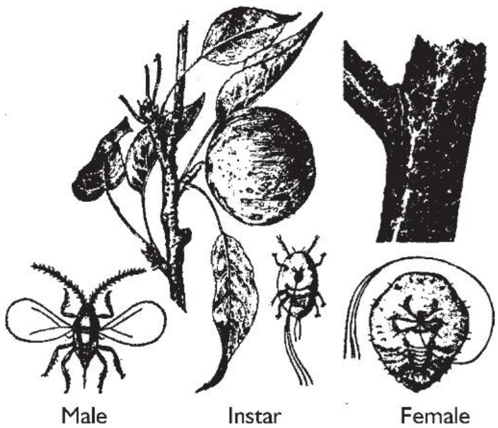
Among the families of Coccoidea this is the largest family comprising a large number of economically significant pest species. The adult female is soft-bodied, small and remains freely under a scale covering formed of wax secreted by its body. The morphology of scales are variable, being circular or elongate, smooth or rough and often variously coloured. The scales of the male is more elongate and smaller than that of the female. The adult female is flattened, disc-like, apodous, eyeless and with antennae either absent or vestigial. Males are winged and short-lived.

The insect reproduces bisexually or parthenogenetically, being oviparous or ovoviviparous. The eggs are laid by the female under the scale covering and the crawlers that hatch out from the eggs move about and attach themselves on the host plant at suitable places and remain stationary during the remaining part of its life.

The scale insects suck the sap and inflict serious injuries to cultivated plants and trees. The San Jose scale *Quadraspidiotus perniciosus* is a notorious pest of fruit trees in many countries of the world.

1. THE SAN JOSE SCALE *Quadraspidiotus perniciosus*

This is one of the notorious introduced pests in India (Fig 57.39). As it was first noticed in a place called San Jose in California, USA, in about 1870 it is known as the San Jose scale. It is a native of China and is found in all countries growing apple. In India it was introduced about 60 years ago and is now found in almost all states. It is a serious pest of fruit trees on the hills in Kashmir, Himachal Pradesh, Uttar Pradesh and Tamil Nadu, particularly on apple, pear, etc.



▲ **Fig. 57.39** *San Jose scale Quadraspidiotus perniciosus on apple (courtesy: USDA, Washington)*

The insects feed on the sap and cause loss of vigour, poor growth and death of plants or trees. Severely infested trees show an ash-grey appearance. The infested fruits become unfit for marketing.

The adult female is round or oval, greyish and measures about 2 mm wide. Its abdominal apex is black and has four lobes. The scale covering is dome shaped with a nipple-like structure on the elevated mid-dorsal point. The male scale is elongated, light amber coloured and smaller with the nipple on one side of the scale. The male soon after emergence mates with the adult female. The adult female reproduces ovoviviparously. The crawlers move about and attach themselves at suitable places on the host tree or plant in a day and each secretes a waxy scale covering which is completed in about four to five days. A female is capable of giving birth to 300 to 400 nymphs and the nymphs attain maturity in 30 to 40 days.

The insect is active from the end of March or the beginning of April and during the period April to December six to seven overlapping generations are noticed. The insect overwinters inside the scale covering.

Control: The nursery stock is the main source of dispersal of the scale insect and it should be free from infestation. In Uttar Pradesh the exotic parasite *Prospaltella perniciosi* has proved to be effective in controlling the pest. Parathion and diazinon have been found effective against the pest. Sprays of the miscible oils, Esso tree spray and Shell winter spray at 2% concentration and methyl demeton 0.1%, formothion 0.2% and parathion 0.05% have also been reported to be effective.

2. THE SUGARCANE SCALE *Melanaspis glomerata*

Distribution: In India it has been reported from Tamil Nadu, Bihar, Maharashtra, Andhra Pradesh, Madhya Pradesh and West Bengal.

Damage: Varieties having persistent leaf sheaths are attacked to a greater extent and a definite correlation exists between the number of stomata in the stem epidermis and the intensity of attack. In a highly susceptible variety of sugarcane the infesfation led to the germination being reduced by about 20 per cent. Further, the weight of canes, juice sucrose content, bulk and purity are reduced by about 13, 47, 28 and 26 per cent respectively. The scale infests the stalk mainly covering the internodes of the stem, but in some cases even infests the leaf sheath and the lamina, including the midrib. The scale insect occurs on five to six month old crop. When the infestation is heavy the entire stem is covered with scales giving greyish black appearance.

Life history: The insect was first collected by Geo Watt from sugarcane and was described by Green in 1903. It is considered to be a native of North India occurring on a wild grass

Saccharum spontaneum. The oval yellowish adult female is a degenerate type and ovoviviparous. The nymphs that hatch out from the eggs after 12–20 days. The hatched out nymphs come out through the genital aperture of the adult female. The number of eggs laid range from 100–400.

They are known as crawlers which after selecting a suitable feeding site settle down and secrete their scale covers. At the next moult they become apodous and become stationary. As the insect grows the scale covering also gets thicker and affords protection to the insect inside. The male scale is more elliptical and smaller in size than that of the female and passes through pre-pupal and pupal stages. The adult male possesses a pair of wings, is short-lived and is able to fertilise only one female. The life cycle ranges from 34-62 days. The number of generations vary and up to six overlapping generations have been reported.

Host plants: Sugarcane (*S. officinarum*), *Saccharum spontaneum*, *Apluda aristata, Erianthus,* and *Sorghum halepense.*

Natural enemies: Parasitoids of the scale in India are—*Adelencyrtus femoralis*, *Anabrolepis mayurai*, *A. bifasciata, Astymachus japonicus, Xanthoencyrtus fullawayi, Microterys delhiensis, Hamusencyrtus mymaricoides, Neastymachus delhiensis* (Encyrtidae,), *Azotus delhiensis, A. chionaspidis*, *Botryoideclava bharatiya* (Aphelinidae) and *Tetrastichus lecanii* and *T. purpureus* (Eulophidae). The coccinellids *Pharoscymnus horni, Chilocorus discoides, C. nigritus* and *Pullus quadrillum* and the mites *Saniosulus nudus* and *Tyrophagus putrescentiae* are predaceous on the scale.

Control: Systematic stripping of leaves reduces incidence of the pest. Insect-free planting material should be used for planting. Spraying parathion or dimethoate or monocrotophos may be useful.

3. THE TAPIOCA OR CASSAVA SCALE *Aonidomytilus albus*

It is a pest of Cassava (*Manihot* sp.) in Africa, Florida, West Indies, Mexico, Formosa, Argentina, Brazil and India.

In India it was first noticed in 1951 as a serious pest of *Manihot utilissima* at Salem in Tamil Nadu and since then it has been observed in other parts of the State on tapioca. The scales are generally found on the stem and occasionally on petioles. They settle in large numbers on the stem and feed on the sap. In the early stage the plants lose their vigour and become stunted and gradually dry up. During infestation the drying up of leaves is followed by complete dessication of the stem and ultimate death of the plant. Dispersal of the insect is by migration of the crawlers.

The apterous and apodous bag-shaped adult female is reddish-purple in colour and is covered dorsally with a mussel shell shaped silvery white waxy scale. The male is well developed with wings and legs. The insect is oviparous. The light pink eggs are laid between the upper scale covering and the lower cottony secretion at its posterior end. Incubation period is four days. The crawlers move about for sometime and attach themselves to the stem of the plant. It attains maturity in 20 to 25 days.

Host plant: So far noticed only on tapioca.

Natural enemies: The coccinellid *Chilocorus nigritus* is predaceous on the scale.

Control: Sprays of parathion 0.05% methyl demeton 0.025%, and malathion 0.1% have been reported to be effective in controlling the pest.

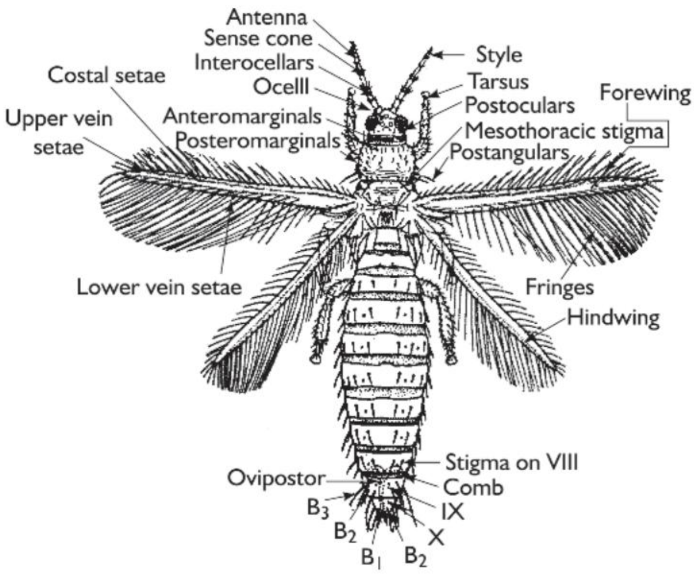
The other diaspidine scale pests of crops in India are: *Lepidosaphes cornutus* on betelvine, *L. piperis* on pepper, *L. becki* on oranges, *Aspidiotus hartii* on turmeric and yam, *A. tamarindi* on tamarind, *A. destructor* on coconut, *Diaspidiotus* sp. on moringa, *Chionaspis vitis* on mango, *Aonidiella orientalis* on mulberry, citrus red scale *Aonidiella aurantii* on *Murraya koenigii* and *Lindingaspis rossi* on rose.

◆ Chapter 58

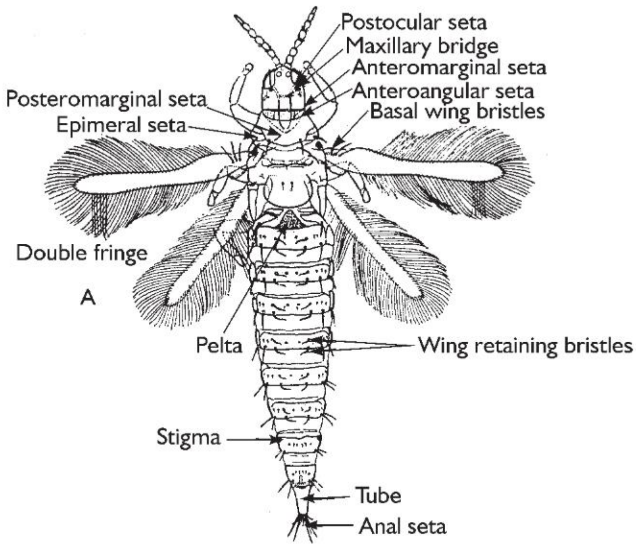
Order Thysanoptera

The order Thysanoptera includes comparatively minute insects ranging from 0.5 to 1.0 mm in size and popularly known as "thrips" or fringe wings. They have also received the name 'Thysapoda" because of the possession of a protrusible bladder-like structure at the end of the tarsus. They are known to be of considerable significance as pests of food plants and horticultural plants and also due to their ability to act as vectors of some bacterial, fungal and viral diseases of plants.

The body is covered by a sclerotised cuticle and the integument often shows characteristic sculpture patterns. The head is typically hypognathous produced below into a mouthcone or rostrum, which may be broadly rounded or pointed. Sutures are absent in the head capsule and the cephalic endo-sclerites are not well developed, only the rudiments being present. Anterior, median and posterior tentorial invaginations are present in the Terebrantia (Fig. 58.1) but in the Tubulifera (Fig. 58.2) only one ridge is present on either side of the frons. The compound eyes are composed of a varying number of ommatidia, from three to four to over 150, being reduced in the apterous species. Three ocelli are characteristic of winged species, reduced in brachypterous forms and absent in the apterous forms. The antennae are six- to nine-segmented, the last two or three segments forming the style in the Terebrantia. Sensory areas are present in the primitive aeolothripid on the antenna, sense cone either simple or forked may be developed, particularly on segments three and four. The mouthcone is formed by the labrum, the labium and the maxillae and extends ventrally between the forecoxae. They are adapted for rasping and sucking and are unique because of their asymmetry, only the left mandible being present and functional, the right mandible being fused with the wall of the cranium during



▲ **Fig. 58.1** *A terebrantian thrips*

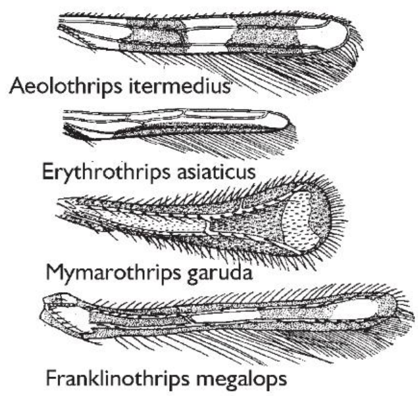


▲ **Fig. 58.2** *A tubuliferan thrips*

development. The labrum is an asymmetrical, oblique triangle and bears a round socket through which the maxillary stylets and mandible pass. The maxillae forming the side walls of the mouthcone carry a pair of triangular palps bearing sclerites and each maxillary stylet consists of three regions–a distal, long, grooved needle-like portion; a middle short and thick portion and an enlarged proximal part which articulates with the maxillary sclerite. The maxillary palps are two- to eight-segmented. The labium is also triangular and broad and it is attached to the maxillae laterally. There is a distinct proximal submentum and distal mentum, which bears the two-segmented labial palp (rarely two- to five-segmented). The left mandible is a long, heavily chitinised, sharp, hollow stylet. The hypopharynx is a median cone, reaching well up under the frons. Maxillary guides are characteristic of the Tubulifera and are supposed to guide the stylets in their action.

The prothorax is well developed, clearly separated from head and mesothorax, and with sutures and an epimeral plate in the primitive aeolothripids. In the Tubulifera there is a large notal plate, at the posterior angles of which are the triangular epimeral plates, completely or incompletely separated. The prosternum is divisible into the probasisternum comprised of two plates and the breast or praepectal plates. The prospinasternum is a small sclerites placed directly under the probasisternum. The meso and meta-thorax are closely jointed and the metathorax with the base of the abdomen. Ventrally strongly developed endothoracic folds or furca are present on the meso- and metathorax. The legs have a two-segmented tarsi (only one-segmented in the larvae), the distal segment ending in a protrusible vesicle or bladder, strongly chitinised at its base. The wings which have well developed fringes exhibit great diversity of structural patterns and longitudinal veins and cross-veins and regular setae on the veins are present in some terebrantians (Fig. 58.3) in particular the aeolothripids, while the venation and chaetotaxy are absent in the wings of the Tubulifera.

The abdomen is made up of ten distinct segments and a rudimentary eleventh. Tergite I is reduced in the Tubulifera and is called the pelta which assumes various shapes in the different genera. Segments VIII to X differ in both sexes, the tergites and sternites of segment IX being fused in the Terebrantia and form a channel ventrally for the reception of the ovipositor. The hindmargin is concave to contain the genitalia. Segment X has a distinct tergite and two small sternite plates; segment XI has a very small tergite, the epiproct and a sternite made up of two lateral plates, the

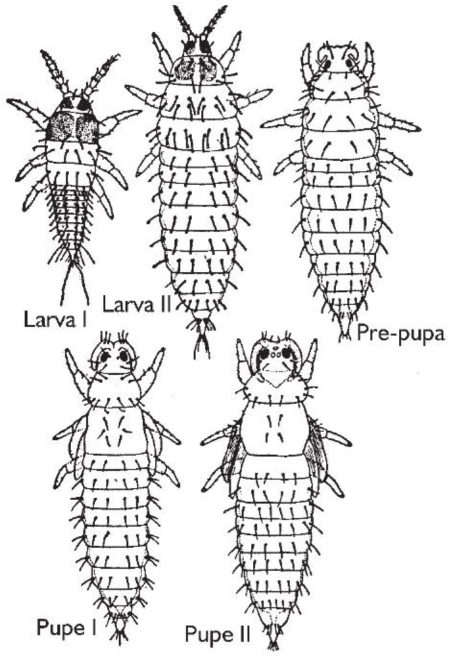


▲ **Fig. 58.3** *Wings of some terebrantian thrips (aeolothripids)* paraprocts. In the Tublifera the segment X is called the tube, which is mostly cylindrical. In all the Terebrantia, the genital opening is placed between the VIII and IX abdominal segments, while in the Tubulifera it is placed between the IX and X segments. The ovipositor in the terebrantian female is made up of two pairs of chitinous valves whose edges bear saw-like teeth and the valves enclose between them the egg channel. An ovipositor is absent in the Tubulifera.

The male genital opening is placed between the IX and X abdominal segments. The genitalia comprises a median chitinous rod, the aedeagus or phallus and the lateral parameres. Attached to the base of the aedeagus is a membranous vesicle, the epiphallus and in the Tubulifera this vesicle is balloon-like and membranous and at its apex is a chitnised rod, the aedeagus. The parameres are short and are confined to the base.

In the alimentary canal the fore-, mid- and hindgut are distinct. The oesophagus in the Terebrantia is a long slender tube reaching the base of the abdomen and short in the Tubulifera ending about the mesothorax. The mesenteron is also shorter in the Tubulifera. Rectal glands are distinct, projecting into the lumen of the proctodaeum. The pharynx is well developed, 'V' like in cross section, the roof of the pharynx being fused with the inner wall of the labrum, while its floor is fused with the wall of the hypopharynx. The salivary glands are normally two pairs, one of them smaller and their ducts uniting to form the mouthcone. In some Tubulifera, three pairs of glands have been reported. Two pairs of malpighian tubules lie freely and longitudinally in the abdomen and are slender and evenly wide. In the nervous system the abdominal ganglia are markedly concentrated, situated in segment II in the Terebrantia and connected with the metathoracic ganglion by connectives. In the Tubulifera it is closely applied to the metathoracic ganglion and connectives are very short. The heart is peculiar, very short and contained in abdominal segment VIII or VII and VIII and from its anterior end arises the dorsal vessel. Four pairs of spiracles are present, the largest on the mesothorax, one on the metathorax and one each on the first and eighth abdominal segments. The testes are compact bodies and are club-like in shape, sometimes more elongate and leading into the vasa deferentia. The ovaries are made up of eight ovarioles and the ovarioles of each side are suspended by a terminal filament of the salivary glands.

Sexual reproduction is more common among Thysanoptera, the females being larger and more abundant than the males. In species such as *Heliothrips haemorrhoidalis, Aptinothrips rufus,* etc. the males are extremely rare. Parthenogenesis is the main method of reproduction in such cases. The females live much longer than the males and there is an overlapping of generations in species like *Thrips tabaci, Caliothrips indicus, Scirtothrips dorsalis,* etc. Some species show viviparity and ovoviviparity, e.g. *Caudothrips, Tiarothrips, Kleothrips* sp., etc. Females of Terebrantia insert their eggs obliquely inside the tender tissues of plants by their saw-like ovipositor, and the eggs are laid singly or in clusters. The eggs of Tubulifera on the other hand are laid openly on the surface of the substratum such as flower bases, in leaf sheaths, under bark of trees, etc. During metamorphosis the Terebrantia pass through two larval instars I and II, a pre-pupal and only one pupal stage, while in the Tubulifera there are two pupal stages–pupa I and pupa II (Fig. 58.4). Pupation may be on the surface of the plant or within the soil. Rarely, as in aeolothripids, there is a silken cocoon. The duration of life cycle varies from 11-23 days in different species according to the conditions of temperature and humidity.



▲ **Fig. 58.4** *Immature stages of a tubuliferan thrips*

The Thysanoptera enjoy a wide range of distribution, being often carried over small distances by the direction of the prevailing wind and by human agency through articles of commerce. They occur on the tender, succulent parts of plants, or under the bark of dead and dying twigs or among decaying leaves of grass feeding on fungal spores. Some of them produce and inhabit plant galls, while others are inquilines living inside galls of thrips or other insects. Though most of them are phytophagous, very few like *Scolothrips indicus, S. sexmaculatus, Karnyothrips flavipes, Franklinothrips megalops* and *Trichinothrips breviceps* are predaceous, feeding on mites, scales, tingids, thrips and psocids. Mycophagous or fungus feeding thrips are also common as in species of *Tiarothrips, Elaphrothrips, Hoplothrips etc.*

Suborder TEREBRANTIA

Female with a distinct ovipositor. Terminal abdominal segment seldom tubular, that of the female longitudinally divided beneath and usually conical; that of the male usually bluntly rounded, never tubular. Wings with microtrichia and forewing with marginal veins and at least one longitudinal vein with regularly arranged setae on veins.

Superfamily AEOLOTHRIPOIDEA

Ovipositor curved upwards; forewings broad and rounded at apex, with two longitudinal veins, front margin without the fringe of long hairs. Antennae nine-segmented. This superfamily is represented by a single family, the Aeolothripidae. Common genera are *Aeolothrips, Melanthrips, Mymarothrips, Franklinothrips, Erythrothrips*, etc.

Superfamily MEROTHRIPOIDEA

Antennal segments moniliform, eight- or nine-segmented, style absent; segments three and four with a sensory area at apex, tympanum-like, without sense cone; fore and hindfemora greatly enlarged; ovipositor weak, abdomen blunt. Only a single family the Merothripidae exists. *Merothrips.*

Superfamily THRIPOIDEA

Ovipositor curved downwards. Wings more or less pointed at apex. Antenna six-to nine-segmented; segments not moniliform; style one to three-segmented. Foremargin of wings with the fringe of hairs present. The families Heterothripidae, Thripidae and Uzelothripidae are included in this superfamily. The members of the Thripidae include several economically important forms which are well known crop pests.

Family Heterothripidae

Antennae without sense cones or with short triangular ones. Antennae nine-segmented. Foretarsus usually with a claw-like appendage at base of second segment. *Adiheterothrips jambudvipae* and *Holarthrothrips* sp.

Family Thripidae

Antennal segments three and four with slender sense cones, which are simple or forked. Antennae six- to nine-segmented. Foretarsus sometimes with a claw-like appendage. The bulk of the Terebrantian species comes under this family.

Subfamily Thripinae

Terminal antennal segments not long and thin; dorsum of body not polygonally reticulate. *Thrips hawaiiensis, Thrips tabaci, Scirtothrips dorsalis, Sorghothrips jonnaphilus, Sciothrips cardamomi, Anaphothrips sudanensis Megalurothrips distalis* are all included in this subfamily.

Subfamily Heliothripinae

Terminal antennal segments long and thin, needle-like; dorsum of body deeply reticulate with polygonal areas. *Rhipiphorothrips cruentatus. Retithrips syriacus, Caliothrips indicus, Heliothrips haemorrhoidalis, Selenothrips rubrocinctus* are all included in this subfamily.

Family Uzelothripidae

Represented by a single species *Uzelothrips scabrosus* from S. America.

Suborder TUBULIFERA

Female without ovipositor. Last abdominal segment in both sexes mostly tubular. Wings without pubescence and venation. Only a single family, the Phlaeothripidae, is known (Fig. 58.5).

Family Phlaeothripidae

Subfamily Phlaeothripinae

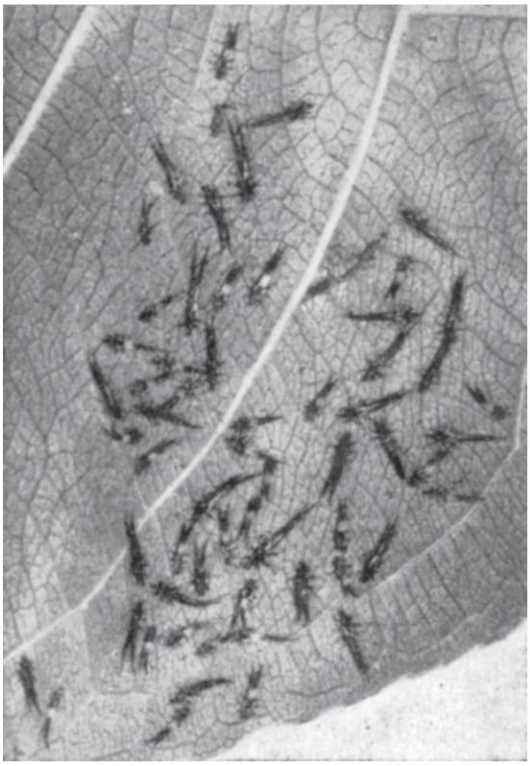
Maxillary stylets slender, never broadened and narrower than labial palps. Distance between hindcoxae less than that of midcoxae. This is a major subfamily with several genera and species. Important genera are *Phlaeothrips, Hoplothrips, Gynaikothrips, Liothrips, Haplothrips*, *Cercothrips,* etc.

Subfamily Megathripinae

Maxillary stylets broadened at apex, broader than labial palps; coxae as above. Includes the bulk of the mycophagous species such as *Tiarothrips subramanii, Kleothrips gigans*, several species of *Elaphrothrips, Nesothrips*, etc.

Subfamily Urothripinae

Distance between hindcoxae greater than between fore and midcoxae, anal setae exceptionally long. *Stephanothrips occidentalis, Baenothrips asper, Bournieria indica,* etc. are included in this subfamily.



▲ **Fig. 58.5** *A group of tubuliferan thrips (Cercothrips nigrodentatus)*

ECONOMICALLY IMPORTANT THRIPS

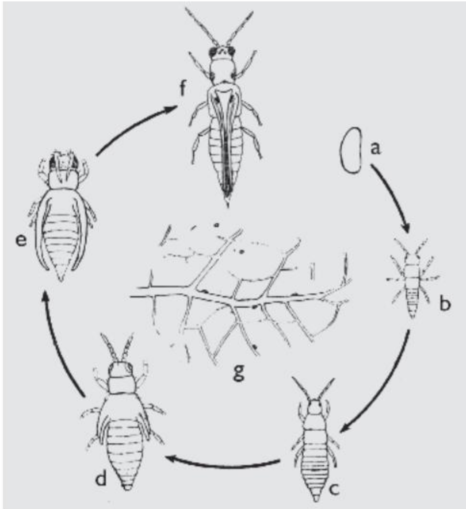
1. THE RICE THRIPS *Stenchaetothrips biformis*

The insect seriously injures rice seedlings. Though sporadic, it is a serious pest of nurseries. The damage caused results in the rice seedlings becoming yellowish with rolled up leaves and ultimately get dried up. It also infests *Echinochloa crusgalli.*

2. THE CHILLIES THRIPS *Scirtothrips dorsalis* (Fig. 58.6)

The chillies thrips is responsible for the leaf curl disease of chillies. They occur in such large numbers that they suck up the sap from the tender regions and cause the leaves to shrivel. In extreme cases the shoot hardly develops and the leaves fall off. Since the adults and larvae infest the tender shoots, buds and flowers, in cases of severe infestation there is malformation of leaves, buds and fruits which may damage half the crop. This species attacks castor heavily, especially tender shoots, flowers and young fruits. The tender leaves of tea are also badly damaged in India and Sri Lanka.

Pairing takes place within 24 hours of emergence. This species reproduces sexually and parthenogenetically, ovipositing within the tissues of tender leaves, a female laying 48 to 50 eggs. The egg is bean-shaped, glassy white, 0.25 mm long and 0.10 mm broad. The incubation period varies from six to eight days. The average total duration of nymphal stage, i.e. 1st and 2nd instars, ranges from four to six days. The total pre-pupal and pupal periods ranges from three to four days. Life-cycle is completed in 13 to 20 days depending upon weather. The female-male ratio is 6:1.



▲ **Fig. 58.6** *Scirtothrips dorsalis: a Egg, b First instar larva, c Second instar larva, d Prepupa, e Pupa, f Adult, g Portion of tea leaf showing position of eggs in the tissues (H. N. Dev, 1964)*

This species also occurs on cotton, tomato, sunflower, mango, *Acacia arabica, Citrus* sp„ groundnut, brinjal, *Albizzia falcata, A. odoratissima, Cassia fistula, Prosopis spicigera,* etc., causing serious damage at times. .

The thrips *Franklinothrips vespiformis* and *Erythrothrips asiaticus* are predaceous on the insect.

Dusting quinalphos 1.5% dust or spray application of dimethoate 0.03% or phosalone 0.07% or carbaryl 0.15% or malathion 0.1% or quinalphos 0.05% or cypermethrin 0.025% four times at monthly interval commencing a month after transplanting affords good control of the insect.

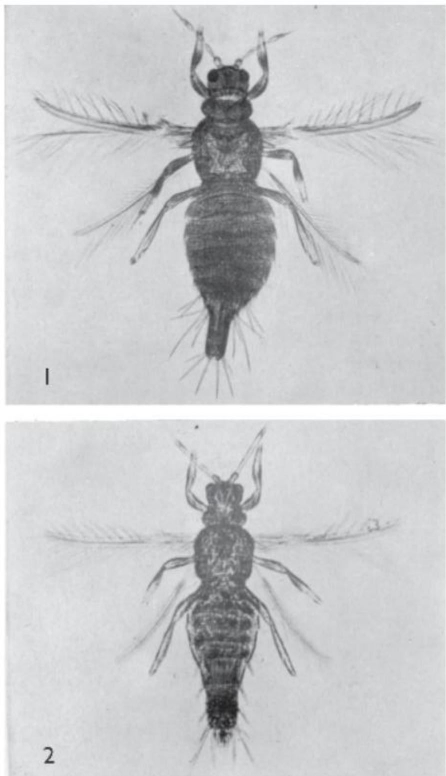
3. THE ONION THRIPS *Thrips tabaci*

The onion thrips or cotton thrips is a highly cosmopolitan form and is found on all kinds of vegetation, a major pest of onions and garlic. As a result of its attack the leaves at first show a spotted appearance and later pale white patches due to the loss of sap, subsequently the leaf tip fades and gradually the lower regions become blighted and the plants ultimately fade and dry up. Partially attacked plants do not develop healthy and good sized bulbs.

They are found on several plants such as cotton and cabbage and is a pest of comparatively low significance. The effect of the attack on cotton is curling of leaves, becoming crumpled and stunted in growth. *Thrips tabaci* has also been known to be vector for the spotted wilt virus and yellow spot viruses. The life cycle is completed in 11 to 21 days. Spray application of carbaryl 0.1%, monocrotophos 0.03% and dimethoate 0.03 % are effective.

4. THE TURMERIC THRIPS *Panchaetothrips indicus* (Fig. 58.7)

This is the turmeric thrips the larvae and adults of which are brown or yellowish brown. They infest the lower surface of tender leaves as a result of which the leaves roll up turning pale yellow and gradually drying up. The rhizomes do not develop or are ill developed.



▲ **Fig. 58.7** *Panchaetorhrips indicus: 1. Female 2. Male (Courtesy: T.N. Ananthakrishnan, 1971)*

5. THE ROSE THRIPS *Rhipiphorothrips cruentatus* (Fig. 58.8)

This is responsible for quite a lot of loss due to the bad quality of grapes, subsequent to the

▲ **Fig. 58.8** *Rose thrips, Rhipiphorothrips cruentatus*

thrips attack. It feeds on the lower surface of the leaves and causes leaf fall. The species is polyphagous and is extremely injurious to rose, country almond, cashew, mango, jamun, etc. Life cycle varies from 11 to 12 days to 11 to 25 days according to weather conditions, both sexual and parthenogenetic types of reproduction being common. Spraying dimethoate 0.03% or malathion 0.05% or ethion 0.05% or quinalphos 0.025% is effective in controlling the insect.

6. THE GROUNDNUT THRIPS *Caliothrips indicus*

It is an important pest of groundnut and onion and also infests a wide range of hosts such as pea, potato, cauliflower, knol-khol, chillies, brinjal, wheat, linseed, cotton, *Foeniculum vulgare, Crotalaria juncea, Sesbania aculeata, Phaseolus mungo, Colocasia antiquorum, Chenopodium album, Convolvulus arvensis,* etc. Copulation takes one to two days after emergence and the pre oviposition period is one to three days. Eggs are laid singly in leaf tissues. During an oviposition period of 17–23 days a female lays 19–96 eggs. Egg is bean-shaped and the incubation period is 6–15 days. There are two larval instars and the larval period ranges from 4–10 days. The pre-pupal and pupal periods vary from respectively one to five and one to six days. Pupation normally takes place in the soil. The adult female is black whereas the male is smaller and light black in colour. The wings are fringed with brown bands. Longevity of adults varies from 21–30 days.

The larvae of *Aeolothrips collaris* feed on larvae of the thrips. *Lasius externenotatus, Scymnus nubilus* and larvae of *Chrysopa* are predaceous on the thrips.

Spraying dimethoate 0.03% or malathion 0.05% or ethion 0.05% or qunalphos 0.025% is effective in controlling the insect.

7. THE COMPOSITAE THRIPS *Microcephalothrips abdominalis* (Fig. 58.9)

▲ **Fig. 58.9** *Microcephalothrips abdominalis (ibid)*

It infests ornamental plants such as chrysanthemum, dahlia, gaillardia, cosmos, coryopsis, zinnia, gerbera, daisy and *Tagetes erecta* and wild plants such as *Tridax procumbens* and *Launea pinnatifida*. Its feeding causes shriveled seeds in addition to injury due to oviposition and scars on the floral parts. Heavy infestation considerably reduces seed production. It also feeds on the fungi *Alternaria alternata, Cladosporium cladosporioides* and *Trichothecium roseum*.

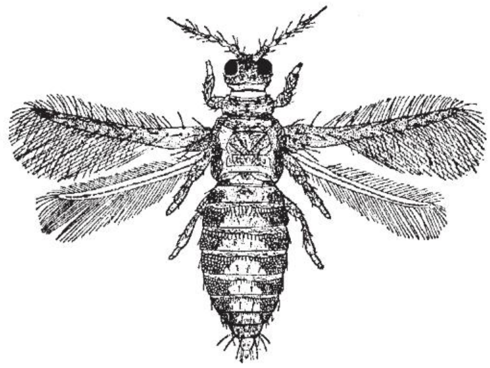
Its life cycle is completed in 9 to 20 days within the flower and reproduction is both sexual and parthenogenetic. There are 20 to 25 generations in a year. Eggs are laid in the flowers especially in the ovary wall. Oviposition period varies from 15–18 days. Unfertilised female lays 47–68 eggs at two to six eggs/day. A fertilised female lays 76–104 eggs at 9–11 eggs/day in 8–14 days. Sex ratio is 4.4 : 1. Unmated female gives rise to males only. Longevity of males and females varies respectively from three to six days and 16–25 days.

8. THE COCOA THRIPS *Selenothrips rubrocinctus*

This is a serious pest of cocoa in the West Indies and in India is found frequently on cashew plants. Badly infested leaves turn reddish brown and gradually fade away (Fig. 58.10).

9. THE BANANA THRIPS *Helionothrips kadaliphilus*

This is the insect feeding in large numbers on the lower side of young leaves in banana plantations causing yellowish brown patches.



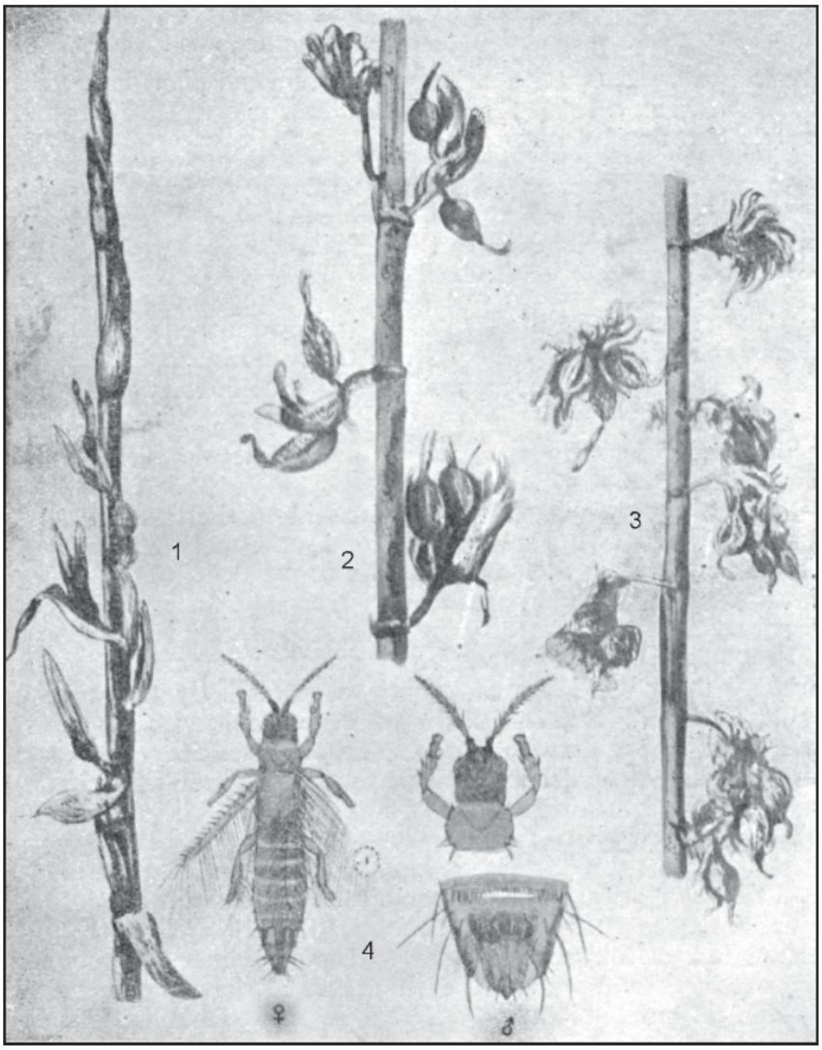
▲ **Fig. 58.10** *Selenothrips rubrocinctus*

10. THE JOWAR THRIPS *Sorghothrips jonnaphilus*

This is the pest of *Sorghum vulgare* all over India; causes numerous feeding patches on the leaves which turn yellowish and subsequently brown.

11. THE CARDAMOM THRIPS *Sciothrips cardamomi* (Fig. 58.11)

The cardamom thrips cause extensive damage to tender blossoms and pods of growing cardamom in South India. All the pods instead of appearing green and shiny, appear stunted,



▲ **Fig. 58.11** *Sciothrips cardamomi*
Left, top above and right: Damaged plants; 4 Bottom middle: Thrips, male and female. (T.V. Ramakrishna Ayyar, Handbook of Economic Entomology for South India, 1940)

malformed, shrivelled and lack the aroma of healthy pods. On an average up to 70 of the affected pods show infestation. Life cycle is completed in 25 to 30 days.

Dusting quinalphos 1.5% dust or methyl parathion 2% dust at 5 kg/ha once a month is generally followed. Sprays of phosalone 0.05%, phenthoate 0.03%, quinalphos 0.05%, profenophos 0.05% are also effective. Being a cross-pollinated crop, primarily by honey-bees, it is desirable to use an insecticide comparatively less toxic to them.

12. THE WHEAT THRIPS *Anaphothrips sudanensis*

The wheat thrips cause characteristic whitening of leaves and this species has an extensive host range. The duration from eggs to the adult stage is about 11-28 days. Reproduction is both sexual and parthenogenetic.

13. THE COFFEE THRIPS *Dendrothrips bispinosus*

The coffee thrips are found in considerable numbers on young leaves in coffee plantations. The life cycle is completed in 15–28 days and about 12 generations are known to occur per year. Reproduction is both sexual and parthenogenetic.

14. THE JASMINE THRIPS *Isothrips orientalis*

The jasmine thrips occur in colonies and badly damage jasmine flowers.

15. THE CASTOR THRIPS *RETITHRIPS SYRIACUS*

This thrips infests castor leares in large colonies and is highly polyphagous, also infesting leaves of cotton, rose, pomegranate, cashew.

16. THE MIMUSOPS THRIPS, *ARRHENO THRIPS RAMAKRISHNAE*

This tubuliferan thrips is found in large numbers within the leaf fold galls of *Mimusops elengi.*

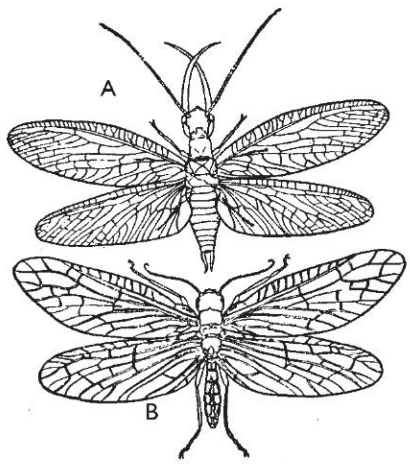
◆ Chapter 59

ENDOPTERYGOTE INSECTS

Order Neuroptera

Ant lions, lacewings, alder flies, snake flies

Neuroptera includes a varied, though interrelated assemblage of holometabolous, carnivorous insects more commonly known as the ant lions, lacewings, snake flies, alder flies and Dobson flies. Principally there are two subdivisions, the Megaloptera including the alder flies and the snake flies and the Planipennia including the ant lions and the lacewings. Some authors prefer to treat the Megaloptera (alder flies and dobson flies) (Fig. 59.1), the Neuroptera or Planipennia (ant lions and lacewings) and the Raphidioidea (snake flies) as distinct orders. As a group the neuropteroids are characterised by the nature of their wings which are membranous and almost subequal with a more or less primitive venation and with many accessory veins, costal veinlets and Rs generally pectinately branched. When at rest they are held over the abdomen. The mouthparts are of the mandibulate type with more strongly developed mandibles in the males and the maxillary and labial palps, five-and three-segmented.



▲ **Fig. 59.1** *A. Male and B. female corydalids (Dobson flies) (from M. S. Mani, Introduction to Entomology, 1955)*

It would appear more appro1priate to discuss the essential characteristics of the various groups in order to have a more comprehensive idea of the Neuroptera in general.

The sialids or alder flies (Sialoidea) with aquatic larvae which are predaceous on other insect larvae like mayflies, stoneflies and dragonflies, and the raphidids or snake flies (Raphidioidea), form the Megaloptera. The adults are large sized with filiform, many segmented antennae, hindwings with a large anal fold, wings without pterostigma with veins usually unbranched at margins and with ovipositor not exserted. The alder flies or sialids are 40 to 100 mm long, while the related dobson flies or corydalids are even larger up to 130 mm long.

The females lay their eggs on leaves or stem or other objects near water, in compact masses, varying from 200 to 250 in sialids to over a thousand in corydalids. The larvae have mouthparts of the caraboid type, with powerful mandibles, and well developed maxillae. At the sides of the abdomen are seven pairs of five-segmented tracheal gills in sialids and eight pairs of mostly unjointed appendages in corydalids. A median terminal filament also functioning as a gill, is seen in sialids and absent in corydalids. In their habits, the corydalid larvae occur under stones in flowing streams, while the sialids occur at the muddy bottom of ponds or slow streams. Pupation usually takes place at depth of several millimetres.

Unlike the sialids, the snake flies or raphidioids are terrestrial, both the adults and the larvae occurring on herbage in forest areas or on tree trunks. They have more elongate slender body, with the head narrow at base to form a neck which leads into an elongate prothorax. The antennae are filiform and many segmented. The clypeus of the head is large. The mouthparts are adapted for biting and with mandibles bearing small teeth. The wings are membranous, subequal and with a well marked pterostigma. The ten-segmented abdomen bears a well developed, long ovipositor in the females, enabling them to insert the eggs within slits in barks. The habitat of the larvae is usually under loose bark and they are voracious feeders on several smaller insects. They are mostly elongate with very well sclerotised head and thorax and without any abdominal appendages. *Raphidia* and *Agulla* (Raphidiidae) have well developed eyes and ocelli, while *Inocellia* lacks ocelli.

The Planipennia is a major group with a vast assemblage of Neuropteran species with large, membranous subequal wings with the typical net-like venation and with branches of veins generally bifurcate at the wing margins or rarely without such bifurcations as in the Coniopterygidae. They are mostly terrestrial and only very rarely the larvae are aquatic. In general, the larvae bear suctorial piercing mouthparts, a feature that is outstanding. The head of the adult bears a pair of very long, many segmented antennae with the segments of various shapes. The mouthparts are mandibulate, the mandibles well developed, as also the maxillae and labium, the former with five-segmented and the latter with three-segmented palps. The mouthparts of the larvae need special mention and the larvae are highly destructive to harmful insects like aphids, the other soft bodied insects, seizing them with the long often armed sickle-like mandibles. The mandibles are grooved ventrally and the maxillae are also modified in that the lacinia assumes the shape of the mandibles and fits into the groove of the mandibles on each side forming a pair of tubes which are inserted into the body of the prey and the contents sucked in with the aid of the pumping action of the pharynx. There are also silk-producing organs, the free ends of some of the malpighian tubules becoming connected with the intestine and producing a silk-like substance in the last instar. The larvae are aquatic only in the family Sisyridae, with seven pairs of segmented abdominal tracheal gills. In others nine pairs of spiracles are distinct.

The coniopterygids which are predaceous on coccids, aleyrodids, aphids, and mites have fragile wings covered with a white waxy powder, with long, filiform antennae. They have bodies narrowed behind and broadened in front. *Coniopteryx pusanus* is predaceous on *Pyrilla perpusilla.* The hemerobids or brown lacewings including the cosmopolitan *Hemerobius* have predaceous larvae feeding on aphids, scales, aleyrodids, psyllids and mites. They have moniliform antennae, and ocelli are absent. The subcosta of the wings does not unite with any other vein at its apex, R_1 and R_3 usually fused and costal area with numerous veinlets. The mouthparts of the larvae are of the typical planipennid type. The eggs are devoid of pedicels. The sisyrids have aquatic larvae with seven pairs of segmentally arranged tracheal gills.

The chrysopids or lacewings have bright green or yellowish brown bodies with wing veins also green, often tinged with brown orange and red colours. The head bears large compound eyes which are iridescent and a pair of long, filiform antennae longer than the body. The wing venation is more complicated with more branchings and cross veins. The eggs are laid in clusters and are provided with elongate pedicels which are attached to leaves and other objects. The larvae have short, broad bodies with well developed sickle-like mandibles and maxillae. Numerous hooked hairs are present on the surface of the abdomen and the larvae usually conceal their identity by covering themselves with the remains of their prey or exuviae, which are retained on the hooked hairs. Though they commonly feed on aphids, they are also known to attack thrips, psyllids, coccids, jassids, etc.

The Mantispidae include neuropterids with an elongate prothorax, short antennae, large eyes and raptorial legs as in mantids. Their life cycle is interesting in that the eggs are pedicellate as in chrysopids and the newly hatched larvae are small, thysanuriform and actively search for and feed on the egg cocoon of the spider *Lycosa.* It feeds on the eggs in the typical neuropteroid fashion, piercing them and imbibing their fluids. On moulting they become transformed into eruciform larvae with very short legs. Pupation is within a cocoon formed by the last larval skin, e.g. *Mantispa.*

The ant lions or myrmelonids are narrow bodied dragonfly-like neuropterids with very narrow wings spotted with brown or black, without pterostigma, with numerous accessory veins and veinlets and short, knobbed antennae. Their larvae called "ant lions" have a hairy body, short head with long, curved mandibles. They lie at the bottom of a conical or funnel-like pit in soft mud and wait for passing by ants which slide down the pit and are caught and sucked up. The common species is *Myrmeleon formicarius* but another species *M. contractus* is reported 'to live on the mud covered trunks of trees and feed on ants. Related to *Myrmeleon* are the ascalaphids which also seize their prey in a dragonfly-like fashion. A very peculiar habit appears to be their protecting of the rows of eggs on grasses, with circular, rod-like structures. The ascalaphid larva also looks like an ant lion. It has well developed dolichasters or segmented processes fringed with modified setae. Another closely related neuropterid is the memopterid *Croce filipennis*, a typical Indian species, with extremely elongate, ribbon-like hindwings, slightly expanded at apex and with head prolonged in front. The larvae are more or less like ant lion, but the neck is distinctly two segmented and have imperfectly developed meso- and metathorax. The mandibles are as in ant lion and they feed on psocids and other small insects.

Suborder MEGALOPTERA (Alder flies and Snake flies)

Larvae with biting mouthparts.

Superfamily SIALOIDEA

Larvae aquatic, with abdominal wings without pterostigma and tracheal gills and ovipositor not exserted.

Family Sialidae

Without ocelli, seven pairs of gills (alder flies) (Fig. 59.2)

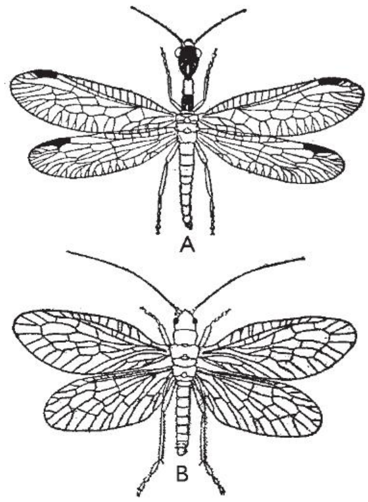
Family Corydalidae

With ocelli, eight pairs of gills (dobson flies) (Fig. 59.1)

Superfamily RAPHIDIOIDEA

Larvae terrestrial, with well developed spiracles, wings with pterostigma and ovipositor exserted.

Family Raphidiidae (snake flies) (Fig. 59.2)



▲ **Fig. 59.2** *A. Rhaphidiid or snake fly, B. an adult sialidfly (from B.D. Moreton)*

Suborder PLANIPENNIA (Lacewings, Ant lions, etc.)

Larvae with suctorial mouthparts.

Superfamily CONIOPTERYGOIDEA

Small forms with fragile wings and covered with a waxy powder. Larva with two segmented antennae and labial palps. Represented by a single family Coniopterygidae.

Superfamily OSMYLOIDEA

This includes three families viz. Ithonidae, Osmylidae and Neurothidae.

Superfamily MANTISPOIDEA

Family Dilaridae

The female possesses a long ovipositor and the eggs laid are not stalked. They live under the bark of dead trees and prey upon eggs and grubs of beetles.

Family Berothidae

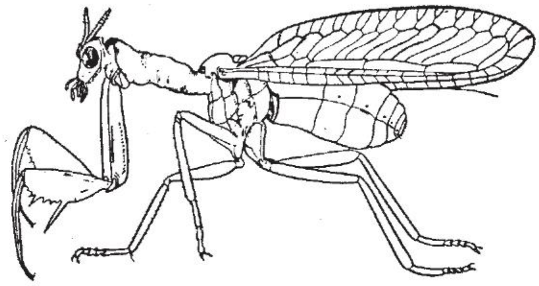
This includes the genera *Rachiberotha, Symphrasis,* etc.

Family Sisyridae

Aquatic larvae with abdominal gills and live on freshwater sponges. Genera include *Sisyra* and *Climacia.*

Family Mantispidae

Adult with elongate prothorax and raptorial legs, serving as an effective prehensile organ. Larvae on hatching are thysanuriform, subsequently eruciform and feed on eggs and cocoons of the spider *Lycosa* sp. (Fig. 59.3). The genera include *Mantispa* and *Plega.*



▲ **Fig. 59.3** *An adult Mantispa sp. (M. S. Mani, 1955)*

Superfamily HEMEROBIOIDEA

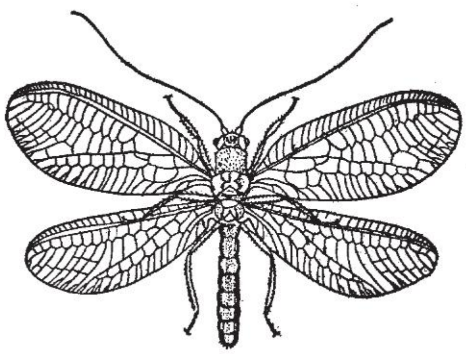
Members of this superfamily are predaceous on aphids and the larvae possess curved jaws which are used for piercing the prey.

Family Hemerobiidae (Brown lacewings)

Small delicate insects with moniliform antennae and without ocelli and ovipositor. Eggs devoid of pedicels and larvae fusiform and smooth.

Family Chrysopidae (Green lacewings)

Adults bright green with iridescent eyes; antennae filiform. Eggs with long pedicels. (Fig. 59.4). Includes the genus *Chrysopa.*



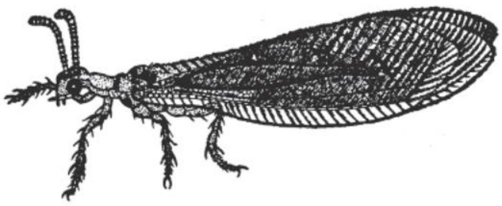
▲ **Fig. 59.4** *An adult chrysopid (ibid)*

Superfamily MYRMELEONTOIDEA

Adults possess long wings and clubbed or thickened antennae. Larva characterised by stout curved mandibles. Includes the families Nymphidae, Myrmeleontidae, Ascalaphidae, Stilbopterygidae and Nemopteridae.

Family Myrmeleontidae (Ant lions)

The adults are generally nocturnal and possess long wings, forewings having a long hypostigmatic cell. The stout larva often lives in a conical pit in which it traps its prey. Represented by the genus *Myrmeleon.* (Fig. 59.5).



▲ **Fig. 59.5** *Adult Myrmeleon (V.A. Little, General and Applied Entomology, Harper & Row).*

Family Ascalaphidae

It is closely related to the ant lions. Adults lack a long hypostigmatic cell on forewing. Genera include: *Ascalaphus, Pseudoptynx, Ulula.*

Family Nemopteridae

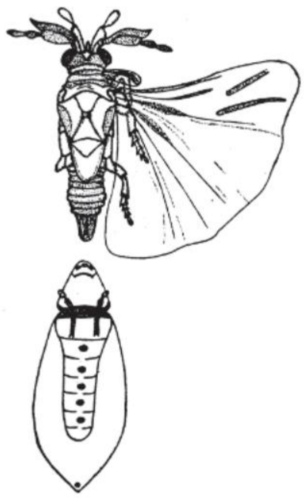
Adults with long ribbon-like hind wings and head prolonged into a rostrum. Antennae long and not thickened or clubbed. Larva with a narrow elongate prothorax and reduced meso- and metathorax. It includes genera like *Croce, Nina, Pterocroce,* etc.

◆ Chapter 61

Order Strepsiptera

Stylopids or Twisted-wing parasitoids

Strepsiptera comprises remarkably small insects whose larvae are known to be internal parasites of members of the family Lepismatidae of Thysanura, Blattidae of Blattodea, Mantidae of Mantodea, Gryllidae, Gryllotalpidae, Tettigoniidae and Tridactylidae of Orthoptera, Delphacidae, Membracidae, Cicadellidae, Cercopidae, Dictyopharidae, Eurybrachidae, Ricaniidae, Flatidae, Fulgoridae, Issidae and Tettigometridae of Homoptera, Coreidae, Cydnidae, Lygaeidae, Pentatomidae and Scutelleridae of Heteroptera, Tephritidae and Platysomatidae of Diptera, Formicidae, Masaridae, Eumenidae, Vespidae, Sphecidae, Colletidae, Halticidae and Andrenidae of Hymenoptera. Economically they are of little or no importance to man as their role in biological control of pest species is very much limited.



▲ **Fig. 61.1** Stylops *male (above), female (below)*

The order Strepsiptera was formed by Kirby in 1813. It is a monophyletic group. The primitive characters as well as the specialisation of Strepsiptera go against their origin from Coleoptera. However, it has been opined that the a great variety of form and number of segments. They may be serrate, clavate, lamellate, moniliform, filiform, geniculate, etc. The number of segments may range from 1 or 2 to 27 or more, though the normal number is usually 11.

Of the mouthparts, the labrum is well developed, but may be concealed behind the clypeus or fused with it as in weevils. The mandibles reach their maximum development in the males of stag beetles or lucanids, where it may be antler-like. It may be longer than the length of the body in some beetles and may be with serrated edges. In the weevils they are only accessory structures with an immovable lobe or prostheca. In the carabids the mandibles are acute, with sharp, cutting edges or bluntly toothed as in most phytophagous forms. The maxillae are very well developed and the palpi are usually four-segmented, rarely three or five. Sometimes the maxilla may be made up of a single lobe or mala as in weevils and nitidulids. The galea is usually palpi-form and two-segmented, while the lacinia is large and blade-like, often provided with sharp, claw-like processes. The labium is made up of a large mentum, the submentum being well developed only in some beetles and fused with the galea in others. The prementum, however, is folded on the mentum. The ligula has a varied structure and may be entire or made up of lobes. The labial palps are three-segmented, rarely bi- or uniarticulate.

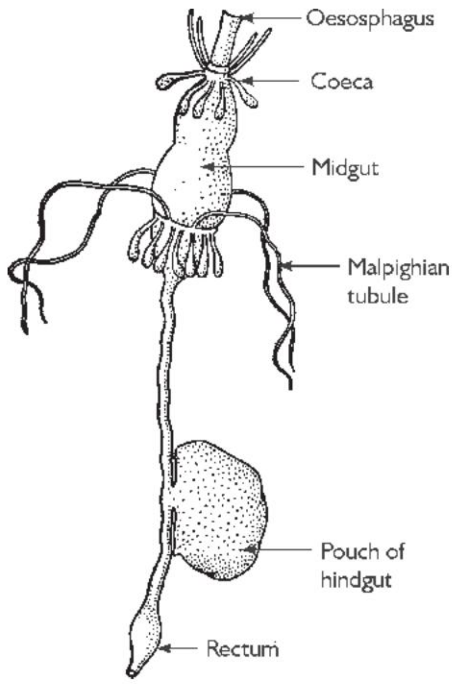
The freely movable prothorax has the pronotum large and made up of a single sclerite. The propleuron is also an undivided plate and in the Polyphaga, the notopleural sutures are absent. But the pleurosternal sutures are distinct, except in the weevils where the prothoracic sclerites are fused. The reduced mesonotum and the metanotum are fused and their terga are clearly divisible into pre-scutellum, scutellum and post-scutellum. The metathoracic furca is well developed and the arms provide attachments for leg muscles. The legs undergo a variety of modifications, being adapted for a variety of functions such as saltatory or jumping, digging or fossorial, natatorial or swimming, though normally adapted for walking or running. In the dytiscids the hind pair of legs are flattened oar-like, while in *Gyrinus* the middle and hind pairs are modified for swimming. The hind femora are elongated greatly and facilitate jumping in the alticids. The tarsi are five segmented in many beetles, but rarely fourth and fifth segments may be united as in weevils and chrysomelids. The number of tarsal segments may also be variable in number in the staphylinids or rover beetles.

The hard elytra or the mesothoracic wings are firmly, immovably united in some Coleoptera as in carabids, weevils, etc. Here the hind wings are absent. In those capable of flight, the hind wings are well developed and during flight the elytra open out, allowing for the proper functioning of the hind wings. In some, as in gyrinids, the pleural region is concealed by the epipleura formed by the reflexed sides of the elytra. The hind wings are of two principal types according to the nature of their venation, the adephagid type with all the veins and cross veins developed, and the staphylinid type with cross veins absent.

In the abdomen some of the proximal segments are not clearly visible. The sterna of first to third segments are reduced and the tergum of the first segment is membranous. Eight tergites and five to seven sternites are distinct. According to the nature of the abdominal sternites, three types of abdomen are recognised–the haplogastrous with a distinct pleurite on the second abdominal segment and reduced lateral sternites; the cryptogastrous with the pleurites of the second segment fused with that of the third segment and second sternite membranous and not visible; hologastrous with the second sternite fully sclerotised and distinct from the third segment. The terminal segments, nine and ten of the abdomen are associated with the genitalia. The male genitalia is typically a tripartite structure made up of a sclerotic tube, the aedeagus and paired, usually movable articulated parameres situated on a basal piece or phallobase.

Stridulatory organs are well developed in many beetles and vary from a file-like area on the head or mandibles to well developed ridges on the femora rubbing against edges of the elytra. In the lucanids a series of ridges are present on the midcoxa, the hindlegs containing the rasping organs. In some cerambycids sound is produced by rubbing the hindfemora against the edges of the elytra.

In the alimentary canal (Fig. 60.1), the pharynx leads into a simple tubular oesophagus, expanding posteriorly into a crop. The crop is rarely absent as in *Mylabris* which feed on pollen grains. In carabids the crop is large and spacious and leads into the gizzard lined by highly sclerotised ridges or with small, fine teeth or denticles and is of considerable significance in the classification. The gizzard leads into the midgut which shows a characteristic appearance, with a large number of small, fine enteric caeca, whose distribution varies with different species. Exceptions are equally common. In meloids the mid-intestine is large and sac-like. In carabids and dytiscids it may be a simple, tortuous tube or a long, convoluted tube. The hindgut is also of varied form. It may be a short tube as in coccinellids and carabids or a long one as in *Dytiscus.* A rectal pouch is very characteristic of dytiscid larvae and adults. A rectum is



▲ **Fig. 60.1** *Alimentary canal of Oryctes rhinoceros* distinct and may bear rectal papillae. There are four to six malpighian tubules. In lampyrids there are four malpighian tubules, each pair uniting distally. In others, their distal ends become closely applied to the walls of the hindgut or rectum and so are not free, thus showing a cryptonephric condition. Though salivary glands are absent in the beetles in general, labial and maxillary glands have been reported in some, as in coccinellids. A number of glands secreting corrosive and pungent substances are present in many beetles. These glands are known as pygidial glands.

The circulatory system has a dorsal heart made up of seven to nine chambers and continued anteriorly into the thorax, head, and the aorta. The respiratory system is most complicated and well differentiated in flying Coleoptera, where the tracheal trunks become greatly branched and often with a system of numerous air sacs, even penetrating the head. In *Lucanus* even the mandibles are filled with air sacs. Ten pairs of spiracles are present and in some weevils the eighth abdominal spiracle is vestigial or non-functional.

The male reproductive system shows two types of testes, the tubular, closely coiled type and the follicular type, with numerous distinctly separate follicles communicating with the vas deferens. The accessory glands are also varied, some arising as ectodermal invaginations, the ectodenia, and the other as mesodermal, the mesadenia, developing directly from the vas deferens. As in the testes, the ovaries also show two types, the Adephaga with polytrophic ovarioles and the Polyphaga with acrotrophic ovarioles. The number of ovarioles vary from 2 to 20 or more. The spermatheca is often present, opening by a long and slender duct into the vagina. A bursa copulatrix may also be present, arising as a diverticulum of the vagina.

Four suborders viz. Adephaga, Archostemata, Myxophaga and Polyphaga are recognised.

The main characteristic features of Adephaga are that the hindcoxae are immovably fixed to the metasternum completely dividing the first visible abdominal sternite. The wings usually show 2 m-cu cross veins. Larva possesses mandibles devoid of a molar area and legs are with a single tarsal segment ending in two (rarely one) claws.

Both Archostemata and Polyphaga are characterised by the hindcoxae not immovably fixed to the metasternum and not completely dividing the first visible abdominal sternite. The Archostemata are distinet from Polyphaga in having wings with the distal part spirally coiled in repose, prothorax with a notopleural suture and larva with mandibles having a molar area and legs with a tarsus and claws, at least in the first stage.

SUBORDER MYXOPHAGA

This includes the only superfamily Sphaerioidea with four families viz. Hydroscaphidae, Lepiceridae, Sphaeriidae and Torridincolidae.

SUBORDER ARCHOSTEMATA

This includes two families viz. Cupedidae (reticulated beetles) and Micromalthidae (micromalthid beetles) and these are not known to occur in India.

SUBORDER ADEPHAGA

This includes a single superfamily Caraboidea. These are mostly predatory in habit and a few are phytophagous.

Superfamily CARABOIDEA

This includes nine families, viz. Rhysodidae, Cicindelidae, Carabidae, Paussidae, Amphizoidae, Hygrobiidae, Haliplidae, Dytiscidae and Gyrinidae, of which the following are of some importance.

Family Rhysodidae (wrinkled bark beetles)

Slender insects, brownish, with moniliform antennae and pronotum with three deep longitudinal grooves; mostly tropical. They inhabit rotten wood. Some species that occur in India are *Clinidium apterum, Rhysodes uterrimus.*

Family Cicindelidae (tiger beetles)

Large active insects, measuring 10 to 25 mm long, brightly coloured, eyes markedly prominent, mandibles large and acutely toothed, long legs adapted for running rapidly, and abdomen ventrally with six visible segments in female and seven in male. They are tropical and subtropical in occurrence and are predaceous on a variety of small insects.

The predaceous larvae inhabit vertical burrows in soil in dry fields or sandy areas and the burrow extends to depths of 30 cm. The larva has a relatively larger head, prothorax, and mandibles. It has a pair of hooks arising from a swollen base on the tergum of the 5th abdominal segment with which it anchors itself firmly to the sides of the burrow. It props at the entrance of the burrow and seizes the insects that pass sufficiently near the burrow which are dragged to the bottom and eaten.

The tiger beetles are extensively found in India and most of them belong to the genus *Cicindela. Cicindela cancellata, C. calligramma, C. cardoni, C. dives, C. duponti, C. sexpunctata, C. undulata, Collyris emarginatus, C. crassicornis, C. fonellii, Prothyma paradoxa,* etc. are some species found in India.

Family Carabidae (ground beetles)

Tropical insects which are found beneath stones, in the soil, in moss and rotting wood, on bark, etc. They are oval, broad, and somewhat flattened beetles exhibiting variation in size, shape and colour. The antennae are conspicuous and project anteriorly. The legs are adapted for running or burrowing, in the former they are long and in the latter they are short and thickened. The elytra in some species are soldered together and the hind membranous wings are wanting; such species cannot fly. Most species are active only at night feeding on other insects and a few are attracted to light. A few belonging to the genera *Ophonus, Zabrus, Omophron* and *Amara* are known to feed on cereals, and seeds of plants, though a majority of carabidae are carnivorous in their larval and adult stages. Beetles belonging to the tribe Brachinina secrete a foul-smelling defensive fluid from the anal end of the body. In some species the fluid volatilises into a gas, the discharge being accompanied by a distinctly audible sound. The fluid has caustic properties.

The larva is elongate, active with the head bearing a pair of sharp calliper-like mandibles and six ocelli on either side, legs ending in a pair of claws, abdomen ten-segmented, the ninth segment bearing a pair of cerci and the tubular tenth-segment generally having a pair of protrusible vesicles.

Some of the more common species found in India belong to the genera *Anthia* (Fig. 60.2), *Agacetus, Calosoma, Macrochilus, Dioryche, Rombus, Amara, Parena, Pheropsophus,* etc. *Pheropsophus sorrinus* var. *desbordesi* (Fig. 60.3) is predaceous on the larvae of the rhinoceros beetle, *Oryctes rhinoceros* found in manure heaps and pits in Assam.

▲ **Fig. 60.2** *Anthia sexguttata*

▲ **Fig. 60.3** *Pheropsophus sorrinus var. desbordesi*

Family Paussidae

Tropical and subtropical beetles, small, red-brown or black in colour, antennae characteristic in being very thick, broad and expanded; elytra truncate and leave the terminal portion of abdomen exposed. They are found mostly in ant nests and sometimes in soil, beneath stones or attracted to light. Like Carabidae, these beetles also discharge a liquid which is irritant to the human skin. Ants lick the secretion eagerly from the body of the myrmecophilous beetles.

The common Indian species belong to the genera *Platyrrhopalus, Merismoderus* and *Paussus*. The nests of the ant *Pheidole latinoda* is inhabited by the beetles *Platyrrhopalus denticornis* and *Ceratoderus bifasciatus* in India.

Family Haliplidae

Aquatic beetles with 10-segmented, bare antennae and legs adapted for swimming. The hind-coxae are produced backwards in a plate partly covering the abdomen. The larvae carry long or short fleshy processes on body and feed on algae in running and standing water. Some common Indian species are *Haliplus angustifrons* and *H. pulchellus.*

Family Dytiscidae (true water beetles or diving beetles)

The family include aquatic beetles mostly found inhabiting running and standing waters. A few live in thermal springs and others inhabit brackish water. They are small to very large beetles, oval in shape, mostly brownish, blackish or greenish in colour. The broad head fits tightly into the thorax and is capable of only slight movements. They possess biting type of mouthparts adapted for carnivorous habit, filiform antennae and functional wings. The insects are capable of long flight. The forelegs in the male of certain genera have three tarsal segments dilated to form adhesive pads provided with cup-like suckers underneath. The tarsal segments helps it to hold the female. The greatly flattened hindlegs fringed with long hairs are adapted for swimming and while swimming, they are moved like oars simultaneously. These beetles carry air in a chamber beneath the elytra and hence they can remain submerged for a longer period. They come to the surface of water for renewing the supply of air. This is achieved by slightly elevating the elytra and admitting air under them. Further, the caudal end of the body is pushed out and the last two pairs of bigger spiracles are put in direct communication with the atmosphere. Both adults and larvae are predaceous on a variety of small aquatic animals including small fishes. The defence mechanisms include a whitish fluid from between the head and the prothorax, and an unpleasant fluid from the anus which are given off when the beetle is caught.

The female oviposits inside the stems of aquatic plants under water. The grub is elongated with a large head having sickle-shaped mandibles with grooves on the inside. These are inserted into the body of the prey and its juice is sucked up. It has legs adapted for swimming, and the abdomen has two open and functional spiracles at its apex. It pupates in mud near the water.

Some common Indian species are *Copelatus indicus, Cybister confusus, C. tripunctatus* var. *asciaticus, Hydaticus vittatus, H. fabricii, Hydroporus aper, Eretes sticticus,* etc. The beetles *Cybister tripunctatus* from China and *Eretes sticticus* from India are edible.

Family Gyrinidae (whirligig beetles)

The family includes small to large, ovoid or elliptical, more or less flattened, steely-black or bronze-lustred aquatic beetles which are mostly gregarious. They keep part of the body submerged and swim on the surface of water round and round rapidly and often also dive under, carrying a bubble of air attached to their hind end. The short, thick, 11-segmented antennae are inserted beneath the front. The eyes are divided into dorsal and ventral portions, the former adapted for aerial vision and the latter for vision under the water surface. The forelegs are long and prehensile, in the male the dilated tarsi are with suckers. The mid- and hindlegs are adapted for swimming. The hindlegs with rigid coxae are greatly flattened.

The adult beetles and their larvae are predaceous. The elongate larvae possess long hollow mandibles, deeply constricted body segments and long, paired, plumose tracheal gills on the first eight abdominal segments. The beetles oviposit on aquatic plants above the water. The larvae pupate in papery cocoons which are fixed to water plants. Some common Indian species are *Dineutes unidentatus, Orectochilus gangeticus*, etc.

SUBORDER POLYPHAGA

The majority of beetles are included under this suborder and they are classified into 18 superfamilies.

Superfamily HYDROPHILOIDEA

Hydrophiloidea are characterised by elongate maxillary palpi which are tactile in function. The antennae are concerned with respiration in aquatic species.

Family Hydrophilidae (water scavengers)

These are tropical insects inhabiting mainly decomposing vegetable matter. They are aquatic or terrestrial. *Helophorus* inhabits glacial ponds, thermal, and chemical ponds on the Himalaya at 5400 m elevation. The beetles are minute or large, black or dull coloured, oval, somewhat convex or flattened. These are with short six- to nine-segmented antennae on the head, sunk into prothorax. Maxillary palpi are often longer than antennae. The foretarsi in the male are adapted for clinging to the female. The mid- and hindlegs are fringed with setae for swimming. In many species the metasternum is prolonged into a sharp spine posteriorly. Some aquatic species are attracted to light. Generally these beetles do not hang head downward from the water surface and while swimming the legs are moved alternately. They carry air on the ventral surface of the body in a silvery film. The larvae are usually predaceous on aquatic animals and are characterised by toothed mandibles and a single tarsal claw.

The eggs are laid in silken cocoons often provided with respiratory tubes and are fixed to aquatic plants at water surface. In some the eggs are fastened to their own bodies. The larvae in many species possess cerci. They usually come out of water and pupate in earthen cells underground.

Some common Indian species are: *Helochares anchoralis, Hydrophilus acuminatus, H. kashmirensis, H. olivaceus, H. piceus, H. senegalensis, H. rufocinctus, Hydrous indicus, Hydrochus binodosus, H. opacus, Coelastoma stultum, C. orbiculare, Allocotocerus leachi, Sphaeridium quinque-maculatum, Pachysternum apicatum, Berosus pulchellus,* etc.

Superfamily HISTEROIDEA

Histeroidea are characterised by geniculate antennae, the three to four terminal segments forming a compact club, truncated elytra and the last one or two abdominal segments exposed. This superfamily includes three families. Sphaeritidae, Synteliidae and Histeridae, of which the last one is a large family of some importance.

Family Histeridae (steel beetles)

The family include minute or medium-sized, broadly oval, compact, hard, shining, brown or black, deeply striated beetles; some with red markings and a few are metallic. The antenna is geniculate and clubbed strongly and rests in a groove beneath the pronotum. The legs are stout, short and fossorial. The elytra are truncated behind leaving the last two abdominal segments exposed.

They inhabit dung, fungi or carrion but apparently feed on other small insects living on them. Several species are termitophilous or myrmecophilous. Some are found in burrows of rodents and land tortoises. *Hololepta* and *Platysoma* are flat beetles found beneath bark and others are cylindrical found in burrows of wood boring insects.

The larvae are soft bodied often with much wrinkled integument and possess no ocelli or labrum. The legs are very short and two-segmented short cerci are borne on the ninth abdominal segment. They are carnivorous on agrotid larvae and saprophagous maggots and Scolytinae.

Some common Indian species are *Hister javanicus, H. daldorffi, Hololepta elongata* and *Saprinus interruptus.*

Superfamily STAPHYLINOIDEA

This is a very large group with usually very short elytra leaving a few last abdominal segments exposed. The venation is very characteristic in that M and Cu are not connected. This superfamily comprises 12 families, viz. Sphaeriidae, Clambidae, Limulodidae, Hydroscaphidae, Ptiliidae, Leptinidae, Anisotomidae, Silphidae, Scydmaenidae, Scaphidiidae, Pselaphidae and Staphylinidae. The following are some common families in India.

Family Silphidae (carrion beetles, sexton-beetles, burying beetles)

The beetles are relatively large, often brightly coloured and possess 11-segmented short clubbed antennae inserted under the front margin. In caverniculous species eyes are wanting but in *Pteroloma* a pair of ocelli is present. The forelegs have large conical coxae which are contiguous, fossorial tibiae with spurs, five-segmented (rarely four) tarsi. These beetles and their larvae occur about the bodies of dead animals and feed on carrion. Some occur in decaying animal matter, some in fungi and a few in ant nests. A few are predaceous on maggots and other insects which are saprophagous. Some Indian species are: *Silpha rufithorax, Nicrophorus nepalensis, Diamesus osculans, Nodynus nitidus, Catops vestita, Aclypea sculpturata,* etc.

Family Scydmaenidae (ant-like stone beetles)

These beetles are small, ant-like, brownish, hairy beetles which occur in moss, under stones and logs and in nests of ants. The hindcoxae are separated and the abdomen is completely covered by elytra. Indian species belong to the genera *Scydmaenus, Eumicrus, Syndicus,* etc.

Family Scaphidiidae (shining fungus beetles)

Scaphidiidae adults and larvae live in fungi, rotting wood, dead leaves and under bark. They are small shiny convex oval beetles appearing pointed at each end. The elytra are truncated exposing the last abdominal segment. Some Indian species include *Scaphidium conjunctum, S. cyanellum, S. lunatum*, etc.

Family Pselaphidae (short-winged mould beetles)

The pselaphids are small, yellowish or brownish beetles with short elytra covering half of the abdomen. They occur beneath stones and logs, in rotting wood or in moss; a few are myrmecophilous or termitophilous. They are predaceous on mites and other small animals. *Mastiger abruptus* is a common species in India.

Family Staphylinidae (rove beetles)

The rove beetles are minute or medium-sized, slender, elongate, black or brownish, somewhat flattened with very short elytra leaving exposed a considerable portion of the abdomen. The well-developed hindwings are kept folded under the elytra at rest. The mandibles are long, slender and sharp and cross in front of the head. Some larger species are capable of inflicting painful bites.

They are active insects which run or fly rapidly. They are found among decaying vegetable or animal matter. Most species are predaceous on saprophagous insects and cannibalistic; a few are myrmecophilous or termitophilous or phytophagous. In India, *Termitodiscus heimi* is found in termite nests and *Tachinus* sp. at the roots of sorghum plants. *Paederus* sp. is predaceous on eggs and larvae of *Euxoa segetum* infesting pea crop. The staphylinid *Atheta hutchinsoni* has been reported to occur on the Himalayas at an elevation of 5600 metres. The other common Indian genera are: *Bledius, Geodromicus, Leptochirus, Myrmedonia, Palaestrinus* and *Staphylinus.*

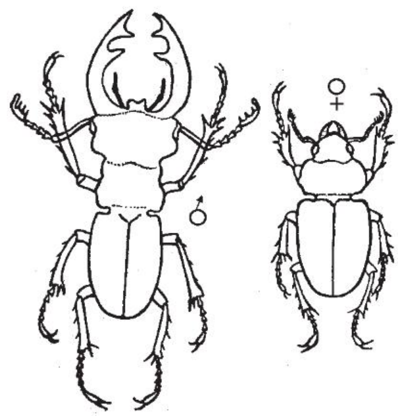
Superfamily SCARABAEOIDEA

The beetles are characterised by the three to seven apical segments of antennae forming a lamellate club. The tarsi are usually five-segmented and the foretibia often toothed or spinose with an apical spur. The exposed pygidium marks the eighth abdominal tergite.

This superfamily includes the following families, viz. Lucanidae, Passalidae, Trogidae, Scarabaeidae, Geotrupidae, Pleocombidae, Glaphyridae, Aegiliidae, Aphodiidae, Melolonthidae, Rutelidae, Dynastidae and Cetoniidae.

Family Lucanidae (stag beetles, stag-horn beetles)

These are large usually black or brown beetles measuring about 3.5 to 10 cm long with large mandibles in males (Fig. 60.4) which are projected forwards and branched like the antlers of a stag. The terminal segments of the geniculate antennae are enlarged, flabellate and cannot be held tightly together. The labrum is indistinct and the mentum conceals the maxillae and the ligula.



▲ **Fig. 60.4** *Lucanus cervus male and female(Jeannel, 1960)*

The beetles usually live in decaying trees and are attracted to light at night. The grubs develop in decaying wood. The giraffe stag beetle *Cladognathus giraffe* occurs in South India and Java. The other Indian species are *Hemisodorcus nepalensis* and *Lucanus lunifer.* The East Indies stag beetle *Odontolabis* *alces* measures over 10 cm long and is the largest stag beetle reported.

Family Passalidae

These are dark brown or black somewhat flattened beetles with elytra having longitudinal grooves. The antennae are not geniculate. The mandibles are not developed specially in males and the mentum is deeply notched. On the head a characteristic horn-like structure is present. The adults are capable of producing a squeaking sound by rubbing the inner surface of its wings on the upper surface of the abdomen.

The elongate grubs develop in decaying wood in forest areas. The hind pair of legs are much reduced with a short coxa and a more elongate trochanter and function as a stridulatory organ producing sound by working across a striated area on the mesocoxa.

Epispheus neelgheriensis and *Ophrygonius cantori* are some Indian species.

Family Trogiidae

These beetles occur in dry places feeding on carrion or dung. The larva lacks stridulatory files. *Trox indicus* and *T. omacanthus* are some Indian species.

Family Scarabaeidae (scarabs; dung beetles)

These are small to very large, smooth, shiny, usually round or oval, very convex, robust beetles with widely separated midlegs, invisible or small scutellum and a spur on hindtibia. Many have spines and horns on the head and prothorax. These are often nocturnal. They feed mostly on dung of mammals which is rolled into balls of convenient size and buried in underground chambers. The beetle also breeds in such dung rolls. A common Indian species noticed is *Heliocopris bucephalus*. The other genera found in India are *Carthasius, Copris, Oniticellus, Drepanocerus, Scarabaeus, Sisyphus, Gymnopleurus*, etc.

THE ELEPHANT DUNG BEETLE *Heliocopris dominus*

This species feeds and breeds exclusively on the fresh dung of elephants. Its development from egg to adult takes place inside a brood ball, lodged in a brood chamber, located in the soil at a depth varying from 27–56 cm. The adults emerge during the first week of June, two to three days after heavy rains. The beetles emerge during early part of night and are attracted to fresh elephant dung pats. They pass through a ‘maturation feeding’ period of approximately four weeks inside separate feeding tunnels excavated below fresh dung pats and packed with dung. Often up to three females dig their separate tunnels below a dung pat. A fully excavated tunnel is elliptical in outline (around 4.5 cm × 4 cm) and descends to an angle of about 45 degree below the surface of the soil to a depth of 27–56 cm. At this level the tunnel opens into a large, ovoid brood chamber of 19–50 cm length, 9.5 to 19 cm breadth and 10–18 cm height. Then the female transports dung from the overlying dung pat into her brood chamber. Each mass of dung that is pushed down is compacted with force against the distal end of the brood chamber. This is repeated until sufficient dung is brought to make three or four brood balls. These are stored in the chamber in the form of a single, compact, smooth, round-ended cylinder measuring 15.50 –39 cm long and 8–10.3 cm broad. It weighs from 880 to 2473 g. No male gets involved in excavation and provisioning the tunnel. Once provisioning is done a male appears in the tunnel. In nests more than 15 days old, the females commence brood construction. The compact dung mass is cut into several masses and each such mass is incorporated into a brood ball containing a single egg. This is done sequentially over a period of several days. Each brood chamber contains generally three brood balls and may vary from two to four. The female continues to live inside her brood chamber taking care of the developing grubs inside their brood balls until they pupate.

Family Geotrupidae ('dor' beetles)

These beetles are characterised by distinct scutellum, approximated midlegs, two spurs on tibia on hindleg, and the three terminal segments of the 11-segmented antennae ending in a lamellate club. They feed on dung and other excrements. They stridulate by rubbing together a file on the hindcoxae and the sharp edge of the coxal cavity.

The common Indian genera are *Geotrupes, Athyreus, Ceratophyses* and *Bolbocerus.*

Family Melolonthidae (cockchafers; June beetles)

The cockchafers are variously coloured, black, brown, green, mahogany, blue or metallic coloured. In the male the antennal club is often elongate and horny processes are present on its head. The mentum and ligula are fused. The metasternum bears laterally the coxae and the abdomen is with six tergites. These beetles are commonly attracted to light.

The larvae feed on roots of plants and trees and are often destructive. The grub is fleshy, white with brown head, curved body and the terminal segment large and smooth.

The beetles are destructive to a wide variety of crops and fruit trees both in their adult and larval stages. In Europe and Western Asia the beetle *Melolontha melolontha* is a very serious pest. In India a number of species of *Holotrichia* are very destructive to crops and fruit trees. *Serica nilgiriensis* on cinchona and *S. pruinosa* on coffee, *Rhizotrogus rufus* on cinchona, *Lepidiota mansueta* on sugarcane.

1. THE SUGARCANE WHITE GRUB *Lepidiota mansueta*

The insect has been reported to damage sugarcane in sandy patches in Uttar Pradesh. The grubs remain in the soil for about 20 months and cause heavy damage by feeding on the roots and underground portions of the stem.

The beetles emerge after monsoon in June and mate. The female after mating gets into the soil and oviposits at depths varying from 2 to 20 cm. The incubation period is 10 to 13 days. The grubs become full grown in about 20 months and measure 45 to 56 mm long. The pupation normally takes place during April-May in an earthen cell. The total life cycle is completed in two years.

2. THE WHITE GRUB *Holotrichia insularis*

This is the most abundant and harmful species of white grub pests noticed in Rajasthan.

The larvae feed on roots of plants. As a result, the plants dry up in the seedling stage. In cases of heavy attack the plants wither and gradually dry up. A grub attacks a number of plants. The adults feed at night on the foliage of trees found in the vicinity.

The beetles emerge in June after the break of the monsoon. They are active at night feeding on the leaves of trees and defoliate them. The common trees defoliated by the adults are *Moringa oleifera, Carissa carandus, Psidium guajava, Azadirachta indica, Zyzigium jambolanum, Lawsonia inermis, Zizyphus jujuba, Tamarindus indica, Acacia arabica, Punica granatum, Mangifera indica, Grewia asciatica* and *Crataeva religiosa.* They mate usually after feeding for about a fortnight and the pre-oviposition period is four to six days. It lays the eggs in the soil at depths varying from 2.5 to 15 cm with two to four eggs in each place. On an average it lays about 30 eggs. The incubation period is 8 to 12 days. The full grown grub is dirty white, fleshy, curved measuring about 41 mm in length and 8 mm in width. It pupates in an earthen cell. The pupal stage lasts for 15 to 22 days. The adults as well as pupae hibernate in the soil from November to June. There is only one generation in a year.

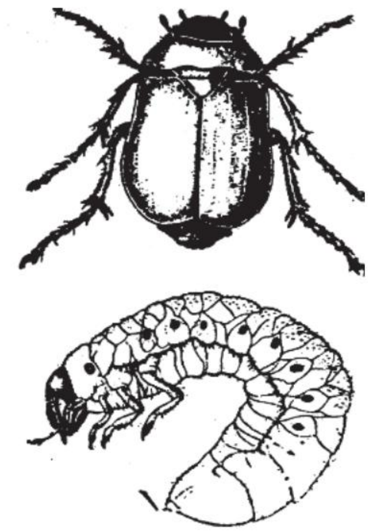
The grubs are destructive to crops like sorghum, *Pennisetum typhoideum*, maize, sugarcane, chillies, peanut, sunnhemp, egg-plant (brinjal), cucurbit, cowpea and *Abelmoschus esculentus.*

Control: Collection and destruction of adult beetles when they are found feeding on the trees and spraying of chlorpyrifos 0.04% or carbaryl 0.1% or endosulfan 0.07% on the trees kills the adults and thus reduce egg laying. Application of quinalphos 5% granule at 50 kg/ha to the soil in June controls the grubs in the soil.

3. THE PALAS WHITE GRUB *Holotrichia serrata*

1This beetle (Fig. 60.5) has been reported to cause widespread damage to some important hosts of the lac insect, viz. *palas (Butea monosperma), Scheleichera oleosa*, *Zizyphus xylopyra* and *sandan (Ougeinia dalbergioides)* at Ranchi in India. It has also been reported to attack teak (*Tectona grandis*), sugarcane and roots of tobacco.

The adult beetles heavily defoliate the trees. The grubs feed on roots of the plants but the damage has been insignificant. In Andhra Pradesh the grubs feed on roots of five to seven weeks old tobacco plants and cause wilting and drooping of plants to an extent of 40 per cent of the affected crop.



▲ **Fig. 60.5** *Holotrichia serrata (A) adult and (B) grub*

The adult beetles come out of the soil at dusk, mate and feed on the leaves of the trees and early in the morning get back to burrows in the soil at 5 to 7.5 cm depth. They are active during May to July and disappear by the first week of August. The beetle lays the eggs during April-July in small cells in the soil at a depth of 12 to 15 cm, a single egg per cell. In an area of one square centmetre, about four to five cells are seen. A female lays on an average about 65 eggs, The pre-oviposition period ranges from 169 to 224 days. However, in a few cases the last instar grubs fail to pupate before winter intervenes and in such cases the pre-oviposition period ranges from 37 to 86 days. The larvae hatch out of the eggs in 8 to 13 days and they feed on roots. They become full grown by September and pupate in earthen cells. The pupal period is seven to ten days. The adults hibernate and become active from April. There is only one generation in a year. The total development period from egg to adult takes 171 days on an average.

4. THE GROUNDNUT WHITE GRUB *Holotrichia consanguinea*

This is a serious pest of groundnut, *Sorghum vulgare* and *Pennisetum typhoideum* in Gujarat (India). The pest is prevalent in its larval stage in the fields from March to October. Drilling of lindane 0.65 per cent dust at 1 kg active ingredient/ha in furrows to a depth of 10 cm at sowing affords appreciable relief.

5. THE COCONUT WHITE GRUB *Leucopholis coneophora*

This melolonthid beetle is recognised as a major pest of coconut in Kerala. The grubs after the pre-south-west monsoon showers in April move to the upper layers of soil and feed on roots near the bole of the palms causing yellowing of palms. Heavy attack results in premature fall of nuts. Apart from coconut, other inter-crops such as tapioca, yam, colocasia, sweet potato and banana are also damaged.

The adult beetles are chestnut coloured with glistening pubescence. They come out of the burrows in the soil in large numbers during the early half of June after the first showers of south-west monsoon. They are active for about eight weeks and oviposit during June-July. The eggs are laid in the soil at a depth of 7 to 15 cm and the incubation period is 20 days. They pupate after ten months of feeding. The pre-pupal and pupal periods occupy 9 to 12 and 25 days respectively.

Control: Application of dust of either endosulfan 4% or quinalphos 1.5% at 120 kg/ha twice a year in April and August can lead to the satisfactory control of the grubs. Deep ploughing of the fields when the pest is in abundance exposes the grubs which are then picked up by birds.

Family Rutelidae (shining leaf-chafers)

These are mostly brightly coloured insects which are metallic green or blue, reddish or golden yellow. They are characterised by unequal claws on hindlegs and a sclerotised labrum. Both adults and grubs are destructive, the former feed on foliage, flowers and fruits and the latter feed on roots. The Japanese beetle *Popillia japonica* is a well known pest of fruit trees in the USA and got introduced into the country from Japan in about 1916.

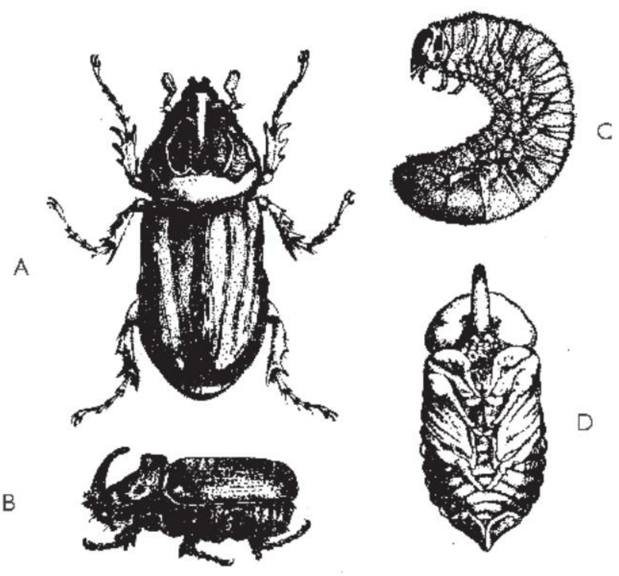
In India the common genera are *Adoretus, Anomala, Popillia* and *Mimela. Popillia chlorion* on cinchona, *Anomala varians* on garden plants and *Adoretus bangalorensis*, *A. bicolor, A. caliginosus, A. stoliczkae* and *A. versutus* on rose are some of the pests belonging to this family.

Family Dynastidae (rhinoceros beetles; unicorn beetles or elephant beetles)

These beetles are very large to medium sized insects, smooth, shiny, brilliantly-coloured and sometimes sculptured. Horns and tubercles are present on head and pronotum and they exhibit great sexual dimorphism. The characteristic feature is the mandibles which are expanded and visible from above. In India the beetles *Oryctes rhinoceros, Xylotrupes gideon* and *Phyllognathus dionysius* are known as pests of palms (including coconut), and paddy respectively. *Heteronchyus poropygus* has been obtained from roots of paddy in Karnataka State.

1. THE RHINOCEROS BEETLE *Oryctes rhinoceros*

This beetle (Fig. 60.6) is one of the major pests of coconut, and has a wide distribution in Asia, Australia and Pacific Islands. The beetle is most widespread and persistent in all coconut growing areas in India. The adult beetles cause severe damage to coconut palms. They live in crevices between leaf sheaths near the crown and burrows into the softer portions. The tender fronds in the folded condition are cut across and when unfolded they bear characteristic clippings or holes in the leaflets. Repeated attack causes stunting of trees. Injury to spathe is also common resulting in loss of nuts directly. Young seedlings are sometimes killed outright when growing points are damaged. The wounds also provide entry for harmful bacteria, fungi, etc. Sometimes the stalk of the frond is also bored. Young as well as old trees are attacked. The fibrous chewed material present near the holes indicates the infestation.



▲ **Fig. 60.6** *Oryctes rhinoceros adult: dorsal (A) and side views(B) larva (C) and pupa (D)*

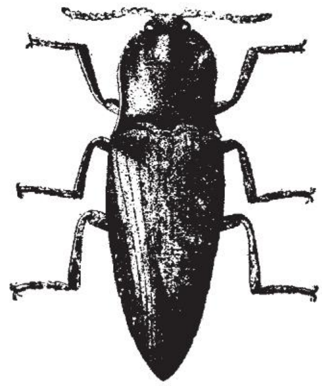
The beetle is about 5 cm long, black or reddish black in colour, stout and possesses a characteristic horn projecting dorsally upward from the head. The horn is long in male and short in female. It breeds in manure pits, undisturbed heaps of decaying organic debris, dead coconut logs, etc. It lays eggs in the breeding material at a depth of 5 to 15 cm. A single female lays up to 140 eggs. The egg is oval, creamy white and fairly big and the incubation period is 8 to 18 days. The grubs feed on the decomposing organic matter and a full grown grub is 9 to 10 cm long, whitish with a pale brown head, fleshy and sluggish. It is found at a depth of 5 to 30 cm. The larval stage lasts for 99 to 182 days.

The grubs seek shelter at the sides and bottom of manure pits and construct earthen cells at a depth of 30 to 90 cm or more. The pupal stage lasts for 10 to 25 days. The adults make their way out and fly to the trees. Life cycle from egg to adult takes 3½ to 8 months. The adult lives for about 290 days. It is abundant during March-May. Occasionally five to six beetles may be present on a tree.

Apart from coconut it attacks talipot palm, date palm, palmyrah, African oil palm, aloe, areca, sago, sugarcane and pineapple.

Control: Burning of decaying coconut logs which may serve as breeding places is essential. The adult beetles may be extracted from the crowns by means of beetle hooks. As a prophylactic measure the inner- most three or four leaf axils may be filled with a mixture of sand and carbaryl dust in equal proportions twice a year during pre monsoon and post monsoon periods. The grubs in their breeding places should be killed by spray application of carbaryl 0.1% at least once in three months.

The eggs and grubs are preyed upon by *Santalus parallelus* and the grubs alone by *Agrypnus* sp. (Fig. 60.7). The exotic predatory bug *Platymeris laevicollis* introduced in the Androth island of Laccadives and at Pandalam in the mainland, appears to have established in the liberated areas. The grubs get infected by the fungi *Metarrhizium anisopliae* and *Beauveria bessiana* during the southwest monsoon season when there will be high humidity and low temperature.



▲ **Fig. 60.7** *Agrypnus sp.*

Family Cetoniidae (flower beetles)

The Cetoniidae are principally pollen feeders and are found under loose bark or in debris and a few are myrmecophilous. The larvae develop in organic matter in the soil and a few infest roots of plants.

These are medium sized to large beetles and the well-known goliath-beetle *Goliathus goliathus* measures 12.5 cm long. They are brilliantly coloured and dorsally flattened with a large scutellum. The mandibles are not expanded and are invisible from above. The labrum is concealed. *Anatona stillata, Anthracophora crucifera, Chiloloba acuta, Oxycetonia versicolor, Protaetia alboguttata* and *P. aurichalcea* are some common Indian species. The beetle *P. aurichalcea* has been reported to feed on pollen stores of *Apis cerana* in hives.

Superfamily DASCILLOIDEA

The Dascilloidea are characterised by filiform or slightly serrate antennae, more or less conically projecting forecoxae with their cavities completely open behind and the hindcoxae excavated to receive the femora. There is a single family viz. Dascillidae.

Family Dascillidae

These are moderate-sized beetles and their larvae generally feed on roots of grasses. In South India *Ora picta* occurs in large numbers on paddy but it does not cause any damage. However, the grubs are aquatic and appear to feed on minute particles of food such as algae or protozoa or bits of organic debris in paddy fields.

Superfamily EUCINETOIDEA

Three families viz. Clambidae, Eucinetidae and Helodidae are recognised.

Superfamily BYRRHOIDEA

This is a small group of insects characterised by deflexed head with no visible clypeus, the coxa of foreleg is large with trochantin exposed, and a prosternal spine which fits into a mesosternal cavity. Two families, Byrrhidae and Nosodendridae, are recognised.

Superfamily DRYOPOIDEA

The Dryopoidea are mostly subaquatic and possess serrated antennae and a prosternal spine which fits in a mesosternal cavity. Some exhibit plastron respiration and show special adaptations.

Eight families, viz. Psephenidae, Eurypogonidae, Ptilodactylidae, Chelonariidae, Heteroceridae, Limnichidae, Dryopidae and Elmidae are known.

Superfamily RHIPICEROIDEA

Adults with strongly flabellate antennae and labrum replaced by a nose-like projection. This includes a single family Rhipiceridae.

Superfamily ARTEMATOPOIDEA

Two families viz. Callirhipidae and Artematopidae are recognised.

Superfamily BUPRESTOIDEA

This includes a single family Buprestidae.

Family Buprestidae (metallic wood-borers)

These are mostly tropical insects and inhabit moist forests. The beetles are minute or large-sized, somewhat flattened or cylindrical and the elytra with a scutellar stria. They are golden, green, bronzy or blue metallic coloured beetles and in view of the splendour of their metallic lustre they are used in embroidery and in jewellery in India and other countries. The beetles possess 11-segmented, short, serrated antennae. The hindangles of the prothorax are not produced backwards and the prosternal spine is received in a mesosternal cavity. The metasternum has a well-marked suture. The thorax and abdomen are firmly united. The tarsi possess membranous expansions.

The larvae of Buprestidae are remarkable in having a greatly developed prothorax, slender hind body and vestigial legs which may be sometimes absent. They bore into stems of plants or trees and a few mine leaves; the majority of them gnaw broad, flattened 'galleries in or beneath bark of trees or in roots.

In India *Trachys dasi* and *T. pacifica* on jute, *T. bicolor* on *Butea frondosa*, *T. virescens* on cotton and lady's finger, *T. ipomoeae* on sweet potato, *T. manseuta* on *Sida* sp. and *Trachys* sp. on *Zizyphus jujuba* and *Barleria cristata* are some leaf-miner pests. *Sphenoptera gossypii* on cotton, *S. perotetti* on groundnut, *Psiloptera fastuosa* on teak and *Belinota prasina* on mango are other buprestid pests known.

1. THE JUTE STEM BUPRESTID *Agrilus acutus*

It is one of the most important pests of mesta (*Hibiscus cannabinus*) in jute growing areas in India. The pest is now in the increase on jute (*Corchorus olitorius*) and another jute substitute crop *Malachre capitata* in Maharashtra and West Bengal.

The infestation results in formation of elongate galls on stems usually towards the basal part of the plants. In jute the galls are mostly confined to a height of 30 cm from the base and measure 6.1 to 18 cm long. Formation of parenchymatous cells of the xylem tissue result in breaking of the stem when there is strong wind. Proper extraction of fibre after retting is made difficult and fibres at the level of gall also get cut. The crop raised in April is damaged heavily. The beetle also attacks *Malachra capitata* and *Hibiscus sabdariffa.*

2. THE BARLERIA LEAF-MINER *Trachys* sp. (nr. *virescens*)

In South India the beetle is known as a pest of the flowering shrub *Barleria cristata.* The adults cut deep notches on the leaves and sepals. The grubs mine into the leaf in between the two epidermal layers and feed on the leaf tissue which results in formation of scorched up blotches. In cases of severe infestation the plants look quite dry. Though the beetle is prevalent throughout the year, its peak period of occurrence is from July to December.

The beetles copulate mostly during the early hours of the day and the pre-oviposition period is two days. Before oviposition, it selects the leaf, scrapes the epidermal hairs and then deposits the egg on the upper surface on the vein near the periphery of the leaf. The freshly laid egg is colourless and turns shining black in about 40 hours. The small flat white grub hatches out from the egg and digs into the leaf without exposing itself. It pupates inside the leaf mine in the centre by fixing itself at the posterior end with the exuviae. The development from egg to adult takes 23 to 26 days, the egg, larval and pupal periods being six to nine, 9 to 11 and six to nine days respectively. The adults live for about two months.

It also breeds on *Ruellia prostrata* and *R. patula.* A black ant *Camponotus* sp. feeds on the egg.

3. FLAT-HEADED PEACH BORER *Sphenoptera dadkhani* Obenberger

It is a major pest on peaches in Punjab, Haryana, and Himachal Pradesh. Both adults and grubs cause injury to peach plants. The first instar on hatching enters into the bark and feed making irregular galleries in the bark. The grown up grubs scrape the sap wood. The adults feed mostly on tender leaves.

Life history: In Punjab, the shining copper hued adults emerge from the pupae by making oval holes in the infested branches. The oval, white eggs laid singly on branches along side the lenticels hatch in 15 days. The fecundity ranges from four to seven eggs. There are four larval instars and the total larval period ranges from 63 to 72 days in the short life cycle larvae and from 187 to 198 days in the long life cycle larvae (winter). The grub is shining white with a dark brown head. It pupates in a cylindrical pupal chamber in the gallery. The pupal period variaes from 6 to 11 days. The total developmental period varies from

72 to 83 days in I and II generations and from 194 to 207 days in the third generation. There are three generations in a year; first generation occurs from—March –July, second from—June–September, and third from—mid September to April next. It remains active from March to October and hibernates in larval stage during rest of the year.

Superfamily ELATEROIDEA

The forecoxae are small with concealed trochantins. The hindangles of pronotum are acutely projecting and a transverse metasterna suture is absent. The hindcoxae are contiguous. This superfamily comprises of the families Cebrionidae, Elateridae, Trixagidae, Cerophytidae, Perothopidae and Eucnemidae, of which Elateridae is of some importance.

Family Elateridae (click beetles, wireworms)

Elateridae are minute or medium-sized, grey, black or brown, elongate, slightly flattened beetles with 11-segmented, usually pectinate, antennae attached near eyes. The prothorax is loosely attached to mesothorax and its sternum is lobed in front. Its process is movable and is received in the mesosternal cavity. The clicking noise is produced when the process is drawn out of the mesosternal cavity and returned suddenly; if the beetle happens to be on its back it gets hurled into the air. The tarsi are five-segmented and end in pectinate, dentate or simple claws. The abdominal segments are free. A few beetles belonging to *Pyrophorus*, which are mainly neotropical, are phosphorescent and emit bright lights in their egg, larval and adult stages.

The grubs are long, cylindrical and slightly flattened and hence the name “wireworms.” An unique feature is the presence of a sclerotised dorsal plate with teeth and hooks on the margins located on the ninth abdominal segment.

The grubs are found under decaying vegetation and in dead wood; some feed on roots of cereals, grasses and crops. Species belonging to *Agriotes, Cardiophorus, Corymbites, Hemicrepidius*, etc. are injurious to crops. In India larva of *Agriotes* sp. feeds on the roots of jute. Potato tubers in the field are damaged by *Drasterius* sp.

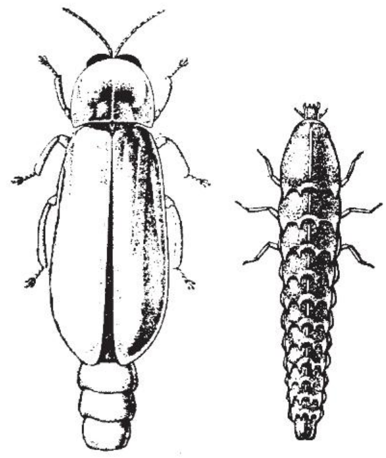
Superfamily CANTHAROIDEA

Cantharoidea are soft-bodied insects with filiform or clavate antennae. They are predaceous in their larval stage and suck the body juice of their victims by means of the internally channeled or perforated mandibles.

This superfamily comprises of eight families, viz. Brachypsectridae, Homalisidae, Karumiidae, Drilidae, Phengodidae, Lampyridae, Cantharidae and Lycidae. The following two families are of interest.

Family Lampyridae (glow worms; fireflies)

These are small or medium-sized somewhat flat, elongate, yellow, black, brown or red coloured mostly luminous beetles (Fig. 60.8). They are nocturnal. The antennae are 11-segmented and may be pectinate or flabellate in male. Eyes are large in male and much reduced in female. The head is more or less concealed by pronotum. The males are winged and the females are often apterous and vermiform. The abdomen is with photogenic organs in sixth and seventh segments in male and only in seventh segment in female, the light emitted being stronger in the latter. The eggs, larvae and pupae are also luminous in some cases. The elongate, flat larva with sickle-shaped mandibles is well adapted for its predaceous mode of life. Adults and larvae are predaceous on other insects, slugs, snails, earthworms, etc. Indian species belong to some common genera such as *Diaphanes, Luciola, Lamprophorus*, etc.



▲ **Fig. 60.8** *Luciola gorhami (left) and Lampyris sp (right) (T. B. Fletcher, 1914)*

Family Cantharidae (soldier-beetles)

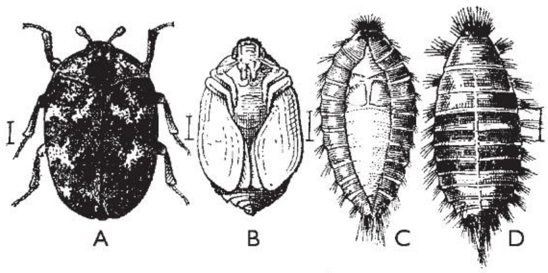
These are elongate, soft-bodied, yellowish, black or brown beetles found feeding on petals, pollen and nectar in flowers; some feed on mealy bugs, aphids and other small insects. The head is not concealed by pronotum. Males are winged and females apterous. They are mostly predaceous in their adult and larval stages. Phosphorescent organs are absent in these insects. The genera included under this family are *Cantharis, Chauliognathus* and *Podabrus.*

Superfamily DERMESTOIDEA

Dermestoidea are characterised by short antennae, generally clubbed and rarely serrate; one or two ocelli often present and the prothorax is not hood-like. This includes four families, viz. Derodontidae, Sarothriidae, Dermestidae and Thorictidae.

Family Dermestidae

Small or moderate-sized oval or hemispherical beetles (Figs. 60.9, 60.10) often clothed with fine scales or hairs. Their larvae are very destructive. The larvae mostly feed on dried animal and vegetable matter and some are predaceous on mantids. They are destructive to furs, hides, horns, wool, bacon, cheese, museum specimens, etc. and hence are considered to be of much significance as household pests. The predaceous forms are generally seen under bark of trees. The larvae are characteristic in having tufts of long hairs on their body. In India the important dermestid household pests are *Dermestes vulpinus*, *Anthrenus flavipes* and *Trogoderma granarium.*



▲ **Fig. 60.9** *The common carpet beetle. Anthrenus sp. A. adult, B. pupa, C & D larvae, (Courtesy: USDA, Washington)*

▲ **Fig. 60.10** *Anthrenus vorax: edges of wool of carpet being eaten by carpet beetles (ibid)*

1. THE HIDE BEETLE *Dermestes vulpinus*

This is a cosmopolitan species. Its larvae are destructive to dead animal matters like carcasses, dried fish, meat, hides, skins and dead silkworm cocoons, wood work of boxes, buildings, ships, books, cork, cardboard, fibre board, stored tobacco, tea, linen, cotton, woollens, salt, sal-ammoniae, lead of fuses and cables, etc. The adult beetles feed on pollen and nectar of flowers.

The adult beetle is shiny reddish brown to black in colour, subparallel in shape and clothed with hair. The males are slightly smaller than females, having a pit and a brush of hair on the fourth sternite and the four short basal tarsal segments of fore-and midlegs lack the fine golden testaceous hair and the tarsal segments also do not form distinct ventral pads.

The beetle lays the eggs in batches of two or three, sometimes singly, and oviposition is favoured under high humid conditions at 25 to 30° C. The number of eggs laid may vary from 198 to 845. The creamy white egg is cylindrical and one end is slightly broader. The incubation period may range from two to four days. The full grown larva is dark brown with a medium yellow stripe dorsally and is densely clothed with hairs. They avoid light. They moult 7 to 14 times and the larval period may range from 25 to 60 days depending on conditions of temperature, humidity and the amount and kind of food. The development is faster in cow, sheep and goat hides and is prolonged in buffalo hide. It pupates in the last larval skin and the adult emerges in about five to eight days. The number of generations in a year may vary from three to six depending upon the temperature and humidity conditions.

2. THE BLACK CARPET BEETLE *Attagenus alfierii*

The larvae of the black carpet beetle are destructive to furs, feathers, hair and wool.

The adult beetle is strongly convex, shining, chestnut brown, compact and oval in shape. In the male the apical segment of the antennal club is much longer than in the female. They mate soon after emergence and the mated female lays the eggs in batches, sticking to one another in rows. The pale white elongate oval egg is slightly broader at one end. The egg period ranges from 5 to 12 days depending upon temperature. The full grown larva is carrot-shaped with a characteristic tuft of hair at the posterior end and densely clothed with brown hairs. They avoid light. The number of larval instars vary from 6 to 25 and the total larval period ranges from 300 to 448 days. Extremely high humid conditions favour larval development. It pupates in the last larval skin and the adult emerges in about 5 to 11 days.

3. THE SPOTTED CARPET BEETLE *Anthrenus flavipes*

The larvae feed on all sorts of dried animal matter and make irregular holes in fabrics. It is widely seen in India.

The small oval beetle is mottled with red, yellow, white and black markings. They are active and attracted to light. It lays the eggs on food materials or in dark secluded places. The elongate egg has a spine-like projection at one end by which it is attached to the surface upon which it has oviposited. The incubation period varies from a week to two weeks depending upon temperature. The larva is elongate to oval and is densely clothed with hairs. It pupates in the last larval skin and the adult emerges in one to two weeks. Depending on the temperature and humidity conditions, and type and availability of food, its entire development period may range from a year to three years.

Control: To prevent damage to plant and insect specimens they should be kept closed in air-tight boxes containing naphthalene dust or a deposit of naphthalene dissolved in benzene. A mixture consisting of creosote (60 drops), rectified spirit (1.12 litres), mercury bichloride (5 g) and carbolic acid (28 g) may also be useful. A saturated solution of naphthalene in one part of CS_2 and two parts of creosote can be employed for cleaning the infested matter. Periodical exposure to strong sunlight, brushing and packing in muslin bags with paradichlorbenzene or naphthalene (3.2 to 4.8 g/cu. m) of materials like furs, blankets, woollen clothings, etc. will be useful. Turpentine is used for cleaning horns. Turpentine with 10 to 12 per cent orthodichlorobenzene can be used for painting stuffed animals and skins. Fumigation of buildings or store rooms with HCN or CS_2 is suggested if infestation is widespread. Spray application of lindane or chlorpyrifos or pyrethrum in deodorised kerosene to cracks and crevices affords relief. Two parts of creosote can be employed for cleaning infested specimens.

4. THE KHAPRA BEETLE *Trogoderma granarium*

It is known to be a major pest of wheat grains in storage. It also attacks dried fruits and other grains. The larvae start feeding on the germ portion of the grains and bores deep into them. The beetle is small, 2 to 3 mm long, ovoid and pale red-brown or black with indistinct red-brown markings on elytra. A female lays about 125 cylindrical white eggs in crevices in godowns or in grain heaps. The full grown larva measures 4.5 mm long and moults four times. It is clothed with long hairs and is yellowish brown in colour. The total development takes about four to six weeks depending up on temperature and humidity. There are about 12 generations in a year.

Superfamily BOSTRYCHOIDEA

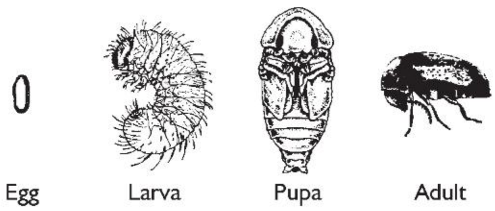
Bostrychoidea are characterised by a hood-like pronotum. Certain species, often associated with timbers, are quite destructive. This includes the following four families: Anobiidae, Ptinidae, Bostrychidae and Lyctidae.

Family Anobiidae

The beetles are small and cylindrical with hypognathous head concealed by prothorax. The three apical segments of the serrate, clavate or pectinate antennae are free and large. The coxa of foreleg is small and conical, opening behind and the grooved hindcoxae receive the femora. They are destructive to wood and some stored products. The larva is fleshy and crescentic with short antennae and generally larger terminal abdominal segments which lack anal processes or cerci. The cigarette beetle *Lasioderma serricorne* and the drug-store beetle *Stegobium paniceum* are well-known pests of economic significance in India.

1. THE CIGARETTE BEETLE *Lasioderma serricorne*

This insect (Fig. 60.11) has a worldwide disribution and is primarily a pest of stored tobacco especially damaging cigarettes and cigars. It also breeds in stored ginger, turmeric, chillies, drugs, etc.



▲ **Fig. 60.11** *Cigarette beetle, Lasioderma serricorne*

The beetle is small, robust, oval and reddish-yellow in colour with the head and prothorax bent downward giving a strongly humped appearance. It measures about 2.5 to 3 mm long. The elytra have minute hairs on them and are not striated. The antennae are uniform throughout their length. The beetle lays about 100 whitish oval eggs. The larva is white, fleshy and crescentic with dense hairs all over its body. The development period from egg to adult takes 30 to 50 days and there may be about six generations in a year. The longevity of adults is 206 days.

2. THE DRUG-STORE BEETLE *Stegobium paniceum*

This species is slightly bigger and more elongate than *Lasioderma serricorne* and its elytra are striated. It is about 2.5 to 3.5 mm long, cylindrical and light brown in colour. A fine silky pubescence covers its body. The antennae are clubbed. The whitish grub is not hairy and is fleshy.

The grubs feed on drugs, stored turmeric, ginger and coriander and dry vegetable and animal matter.

Family Ptinidae (spider beetles)

These are small, cylindrical beetles with filiform antennae and with contiguous fore- and midcoxae and transverse hindcoxae. They are mainly scavenging beetles as they feed on dead insects, excrement or dry vegetable matter. Some feed on stored products and the store-house beetle *Gibbium psylloides* is well known.

Family Bostrychidae

These beetles are small or large, black or reddish brown, elongate, cylindrical, with hood-like pronotum concealing the hypognathous head, clubbed antennae and smooth or variously sculptured elytra sloping and toothed posteriorly. The coxae of forelegs are large and continguous. The larva is characteristic with reduced head and enlarged thorax. These insects make cylindrical burrows in felled timber and dried wood and also infest unhealthy trees. It is interesting that the dead wood infesting insect *Scobicia declivis* often bores into the aerial lead of telephone cables, and water that enters through such bore holes short-circuits; hence the name lead-cable borer or short-circuit borer for the insect. The cosmopolitan insect *Rhyzopertha dominica* is a serious pest of stored grains. Bamboo and felled trees are damaged considerably by species of *Sinoxylon* and *Dinoderus*. Furniture are damaged by *Heterobostrychus aequalis* and *Sinoxylon sudanicum*.

1. THE LESSER GRAIN BORER *Rhyzopertha dominica* (Fig. 60.16)

The insect was first described in 1792 from specimens obtained in South America in a shipment of seeds from India. It is now widespread in many parts of the world.

The beetle is small, slender, cylindrical, polished dark brown or black with a somewhat roughened surface and measures about 4 mm long. The large head is bent under the thorax and the posterior end of the body is blunt. It lays from 300 to 500 eggs singly or in clusters on grains or in powdery matter. The grubs feed by boring directly into grains or unhusked paddy and also feed on flour formed due to earlier feeding. It completes its development either within the grain or in the flour. Its development from egg to adult takes about six weeks.

It is a major pest of unhusked paddy and wheat in India. It also damages sorghum, maize and to a lesser extent wood and paper.

2. THE FURNITURE BEETLE *Heterobostrychus aequalis*

A common species which attacks packing cases, plywood chests and panels, furniture and fittings of buildings.

The black, cylindrical beetle has curved projections on elytra at the posterior end. It lays eggs singly, on roughened surfaces of the timber or in short tunnels made in them. The grubs bore into the timber and make irregular galleries packing them with fine dust of wood and excrement. The grub pupates at the end of the tunnel. The adult beetle which emerges after pupation feeds through the wood and reaches the surface. The development period may range from one to six years depending upon the temperature and humidity conditions.

3. THE BAMBOO SHOT-HOLE BORER *Dinoderus ocellaris*

It is a small, cylindrical, brownish beetle with minute bristles and sculpturing on elytra. It is about 3 to 4 mm long. It bores deep into felled bamboo and bamboo furniture.

The elongate, elliptical, whitish eggs are laid in holes or depressions on bamboo. The incubation period is about five to six days. The grub bores into the interior of the bamboo or wood and makes irregular holes. It pupates in the tunnel itself. The adult on emergence also feeds for sometime and then comes out either through the rind near its pupal cell by making a hole or by the original entrance hole. Three to four generations may be noticed in one year.

Dinoderus brevis and *D. pilifrons* also occur in India.

Control: Infested materials should not be used for making furniture. The furniture should be properly maintained by periodically varnishing, and polishing or painting. Fumigation of infested material with methyl bromide and surface spray application of chlorpyrifos may be useful.

Family Lyctidae (powder post beetles)

The powder post beetles are small, elongate, smooth or pubescent, black, brown or yellow insects with deflexed head not covered by pronotum and two-segmented antennal club. The larva is characteristic in having a more retracted head and a large spiracle on the eighth abdominal segment. These beetles are destructive to wooden furniture, freshly cut wood, old timber and dry wood.

Lyctus africanus is a common species in India. It is a small, slightly flattened reddish-brown beetle, attacking non-coniferous timbers, hard wood, wooden articles and furniture. It has also been reported to attack stored roots of medicinal plants such as *Derris robusta* and *Glycyrrhiza glabra* (Liquorice). The beetle is known to infest the timber of a large number of species of trees. Immunity of conifers to *Lyctus* attack has been attributed to absence of starch in the wood.

Superfamily CLEROIDEA

The members of this superfamily are characterised by five-segmented tarsi, lack of femoral plate on hindcoxa and the prosternal process not being received by the mesostemum. This comprises the families Trogossitidae, Chaetosomatidae, Cleridae, Melyridae and Phloiophilidae.

Family Trogossitidae

Mostly tropical species, elongate or hemispherical, cylindrical, 5 to 20 mm long, head and pronotum large, elytra not truncate, metatarsus short and inhabit decaying trees. Mostly they are predaceous on larvae of other insects. Some of the species feed on fungi. The beetle *Tenebrioides mauritanicus* is a pest found in stored flour, grains, etc. Its larvae are called “cadelles” and feed on grains and prey upon other stored product pests found in association with it. Usually the stored product pests encountered are the bark gnawing beetles.

1. THE ‘‘CADELLA” BEETLE *Tenebrioides mauritanicus*

It has a world-wide distribution. In India it is mostly found in flour mills. They feed on every kind of food grains and also prey upon the rice weevil *Sitophilus oryzae.*

The beetle is black and 8 to 14 mm long. The female lays 500 to 1200 eggs in batches of 10 to 60 eggs. The egg is white and cigar shaped. The greyish-white grub has a black head, black dotted thorax and a pair of short black hooks at the posterior end of the body. The period of development from egg to adult varies considerably depending upon temperature, humidity and availability of food. The adult is capable of living for 15 to 22 months.

Family Cleridae (checkered beetles)

These include mostly tropical insects, beautifully coloured and covered with a dense pubescence. They inhabit tree-trunks or plants; a few occur in carcasses and skins. The tarsi are five-segmented and in many the first or the fourth segment is short. The adults and larvae are mostly predaceous on bark boring Coleoptera; some are saprophagous. In South India, the clerid beetles *Dasyceroelerus erinaceus* and *Ommadius nilgiriensis* are predaceous on scolytid beetles.

Superfamily LYMEXYLOIDEA

This includes a single family Lymexylidae.

These are soft-bodied elongate insects with long flabellate palpi in male, and larva with enlarged prothorax and without paired processes on the ninth abdominal tergite. They bore into hard wood and drill cylindrical holes. In India *Atractocerus reversus* is a pest found in forest trees.

1. THE SALAI BORER *Atractocerus reversus*

The wood of the forest tree *Boswellia serrata* (*Salai* wood), which is utilised in paper industry and in making match-boxes, is attacked by the beetle soon after felling. In green and sappy logs, this borer excavates large and curved cylindrical galleries deep into the centre of wood. The larvae eject out wood dust and feed on the sap and also on fungi which grow on the walls of tunnels. The badly damaged timber is unfit for use.

The log should be debarked immediately after felling. Deep stacking of logs must be avoided. Uniform rapid air-seasoning of logs is essential. The logs, if not extracted immediately, should be swabbed with cresote at the cut ends. Spray application of lindane or 0.02 per cent chlorpyrifos may be suggesed so a temporary precautionary measure.

Superfamily CUCUJOIDEA

Section: CLAVICORNIA

This section includes about 20 families and following are of some interest.

Family Nitidulidae (sap beetles)

These are small, elongate or oval insects with tarsi 5-5-5 and rarely 4-4-4. The fore-and midcoxae are transverse with exposed trochantins. The elytra are short and expose the one or two abdominal segments, which are terminal. Usually, there are six functional spiracles in the abdomen. These may rarely be five in number.

A large number of nitudulids inhabit flowers or are found where plant fluids are fermenting or souring. They occur in fungi or in decaying animal and vegetable matter. A few occur beneath loose bark of dead logs. The larvae of *Meligethes* are known to be phytophagous on Cruciferae and those of *Cybocephalus* predaceous on coccids. In India *Carpophilus dimidiatus* is a very common species found on decaying vegetable matter and flowers. *Cybocephalus semiflavus* has been found in association with mealy bug on sandal trees and mites on arecanut trees in Karnataka State.

Family Cucujidae (flat bark beetles)

The beetles are reddish, brownish or yellowish, and extremely flat, often with filiform antennae. They are usually found beneath bark of trees. Most of them are predaceous on coccids and mites. Some species, which are parasitic on the larvae of Cerambycidae and Braconidae, exhibit hypermetamorphosis. *Laemophloeus* species is both predaceous and grain-eating. *Laemophloeus minutus* is a common pest found in stored products attacking broken grains secondarily.

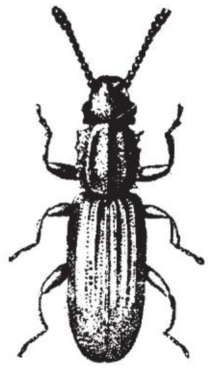
Family Silvanidae (flat grain beetles)

Adults are small, elongate, flat, usually less than 3 mm in length with usually clubbed antennae. Tarsi are 5-5-5 in both sexes. Some beetles occur beneath bark of trees and others feed on stored grains or meal. The saw-toothed grain beetle *Oryzaephilus surinamensis* is a pest of stored grains found in India and other countries.

SAW-TOOTHED GRAIN BEETLE *Oryzaephilus surinamensis*

The insect is small, very slender, flattened, dark red in colour and the lateral margins of the pronotum bear six saw-tooth-like projections on each side (Fig. 60.12). The insect was first described in 1767 from specimens received from Surinam. They produce scarring and roughening of the surface of food. Its attack upon stored seeds usually follows that of other insects, since it is not able to attack healthy seeds. It feeds on a variety of stored materials such as dried fruit, flour, etc.

The adult beetle may live for about three years, the average period of longevity being six to ten months. A female lays 45 to 285 small, whitish eggs, which are dropped loosely among stored food. The incubation period may vary from 5 to 14 days depending upon temperature, humidity, etc. The larva is white with a brown head and the larval period occupies 12 to 70 days. It pupates in a delicate cocoon-like covering by webbing together small grains or fragments of food materials with a sticky secretion. The adult beetles emerge in about 6 to 30 days. In a year there may be about four to six generations. The life-cycle is lengthened during cold weather period.



▲ **Fig. 60.12** *Oryzaephilus surinamensis*

Family Cryptophagidae (silken fungus beetles)

Adult are 1 to 5 mm long, elongate to oval, yellowish brown and covered with a silky pubescence. Tarsi usually 5-5-4 in male. They mostly feed on fungi and a few occur in nests of wasps or bumble bees. *Leucohimatium elongotum* has been found in stored finger millet (*ragi)* in Karnataka State.

Family Languriidae (lizard beetles)

These are small, narrow and elongate (5 to 10 mm long) beetles with reddish pronotum and deep, blue green or black elytra. The coxal cavities of forelegs open behind. Tarsi are never 5-5-4. The claws are simple. The adults feed on leaves and stems of plants. The larvae bore into stems and cause damage. The grubs of the beetles *Anadastus parvulus* bore into stems of *tenai* (*Setaria italica*) and cause dead hearts or drying up of ears.

Family Phalacridae (shining flower beetles)

These small, shining, convex beetles measuring 1 to 3 mm long are usually brownish or black and oval in shape. The coxal cavities of forelegs are open behind: tarsi 5-5-5, the second and third bilobed and fourth small. Tarsal claws are toothed and appendiculate. The larvae of the genus *Phalacrus* develop on smuts on sugarcane, grasses, etc. The species of *Olibrus* are known to be phytophagous in the heads of plants of the family Compositae.

Family Coccineilidae (lady bird beetles)

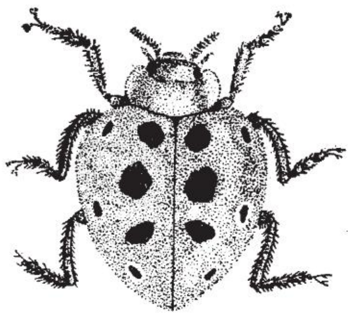
This is a well-known and widely distributed group of insects. The adults are small or medium-sized, oval or round, convex, often brightly coloured red, black, yellow or brown and variously spotted and the head is partly concealed by pronotum. The tarsi are 4-4 4, the deeply bilobed second segment concealing the third segment. Wide range of variations in colour and patterns within the same species occur notably in *Adalia* and *Cheilomenes sexmaculatus.*

They are mostly predaceous in their larval and adult stages on aphids, coccids, aleyrodids and mites, and occasionally on psyllids. Those belonging to the genus *Epilachna* and *Henosepilachna* are phytophagous and destructive to crops. *Afidentula minima* has been observed to feed scraping the leaf blades of finger millet, *Eleusine coracana* in Gujarat. A few feed on mildew or pollen. Most of the members are beneficial as they exercise natural control of harmful species in the field. Frequently the adults are noticed in large aggregations under leaves or in debris and they hibernate as adults.

The grubs of coccinellids are elongate, somewhat flattened, usually brightly coloured, spotted or banded and covered with minute tubercles or spines.

The cottony cushion scale *Icerya purchasi* on citrus in California was effectively checked by the introduction of the predatory beetle *Rodolia cardinalis* from Australia. In India, the same insect on wattle plants and others in the Nilgiris was controlled by the introduction of *R. cardinalis* from California and this is a classical example of biological control.

A large number of coccinellids are predaceous on aphids, coccids, mites, etc. in India and the following are some of the common species. The most common species is *Cheilomenes sexmaculatus,* which is predaceous on aphids, mealy bugs, sugarcane aleyrodid, citrus psyllid, on early instar larvae of the sorghum stem borer *Chilo partellus* and mites. *Coccinella* spp. (Fig. 60.13) feed on aphids. *Brumoides suturalis,*



▲ **Fig. 60.13** *Coccinella septempunctata*

Nephus spp. and *Pullus* spp. are predaceous on aphids and coccids. *Rodolia* sp., *Cryptolaemus montrouzieri* and *Chilocorus nigritus* feed on coccids. The grubs of the beetle *Synia melanaria* are predaceous on the nymphs of the pentatomid bug *Coptosoma ostensum* occurring on *Butea frondosa.* Mites are preyed upon by *Stethorus pauperculus.*

Among the phytophagous forms *Henosepilachna vigintioctopunctata* and *Epilachna implicata* are destructive to Solanaceous and Cucurbitaceous plants respectively. The mildew are fed upon by *Thea cincta. Alesia discolor* feeds on pollen of rice and other plants.

THE SPOTTLED LEAF BEETLE *Henosepilachna vigintioctopunctata* (Fig. 60.14)

This is a polyphagous species, the grubs and adults of which, feed on the leaves of brinjal, potato, tomato, etc. by scraping in a characteristic manner leaving the veins intact. Sometimes it causes extensive damage to brinjal plants.

▲ **Fig. 60.14** *Henosepilachna vigintioctopunctata. Top- Egg mass on leaf, Middle- Grubs feeding on leaf, Bottom- Adults (courtesy: A. Babu)*

A female lays around 120 to 180 elongate, spindle-shaped, yellowish eggs on the lower surface of leaves, in groups of 10 to 20. These are placed in a vertical position. The incubation period is two to four days. The grub is somewhat flat with branched spines all over its body. It pupates on the leaf itself and the pupa is short, yellowish with anterior portion devoid of spines and posterior portion spiny. The adult emerges in a week. It is hemispherical, smooth and brown with 12 to 28 black spots on elytra. The life cycle takes 17 to 50 days depending on the weather.

The insect's hosts are *Solanum melongena* (brinjal), *S. tuberosum* (potato), *S. indicum, S. nigrum, S. xanthocarpum, S. torvum, S. aviculare, S. surrattensis, Datura metel, D. innoxia, Winthemia somnifera* and *Lycopersicum esculentum* (tomato). The eulophid *Pleurotropis epilachnae* is parasitic on the insect.

Control: If infestation is light the different stages of the beetle may be collected and destroyed. Spraying chlorpyrifos 0.05%, porfenophos + cypermethrin mixture at 0.044%, carbaryl 0.1%, methyl parathion 0.05%, malathion 0.05%, fenitrothion 0.05%, etc. is effective.

Section HETEROMERA

This section includes about 24 families and the following are some important families.

Family Tenebrionidae

This is one of the largest families of Coleoptera. They are small or large, elongate, somewhat flattened, usually black or sometimes reddish-brown, hard, often sculptured beetles resembling superficially the Carabidae. Very often they are wingless or with vestigial wings. The elytra are frequently fused. Tarsi 5-5-4, heteromerous and claws are simple. These are usually nocturnal beetles which feed on decaying vegetable and animal matter, dung meal, flour, dried seeds, cereals and other stored products. A few occur in ant nests. The larvae are elongate and cylindrical and often bear two dorsal hooks on hindend and a ventral retractile process.

The red flour beetle *Tribolium castaneum* (Fig. 60.16), *Latheticus oryzae* and *Tenebrio monitor* are well-known pests of stored products. The beetle *Alphitobius laevigatus* feeds on coffee husks and bits in godowns and on stored seeds and dry tamarind fruits. *Gonocephalum hoffmanseggi, G. depressum* and *Opatrum* sp. are pests of grapevine and potato. *Mesomorphus villiger, Opatroides frater* and *Seleron latipes* damage newly transplanted tobacco seedlings. *Palorus shikhae* feeds on broken grains and both adults and larvae prey upon the larvae of other storage pests, viz. *Tribolium castaneum, Oryzaephilus surinamensis* and *Laemphloeus minutus* in rice. The tenebrionid *Gonocephalum depressum* has been reported to be a vector of some of the larval helminths of fowls, such as *Subulura minetti*, the pinworm of fowl.

1. THE TOBACCO GROUND BEETLE *Mesomorphus villiger*

The adults of the beetle damage the newly transplanted seedlings by nibbling or gnawing at the base of the stem resulting in subsequent death of plants. In cases of severe attack, replanting may be necessary. It is a major pest of tobacco in Andhra Pradesh.

The beetle is grey and measures 8 to 9.5 mm long. The beetles generally emerge in February and damage the ensuing tobacco crop in the field. The adults are seen throughout the year. The eggs are laid mostly during October-November and the population of the grubs is at its maximum during November-December. The beetle lays white, oval eggs singly in the soil. The pre-oviposition and oviposition periods generally range from 60 to 100 days, and up to 140 days respectively. It lays the eggs for four to five days at intervals of 15 to 20 days. A beetle is capable of laying as many as 100 eggs. The incubation period ranges from two to ten days. The larvae are negatively phototropic and feed mainly on organic matter in the soil. There are 5 to 14 larval instars, the total period ranging from 31 to 150 days. It pupates in the soil and adult emerges in about ten days. The adult lives for 2 to 190 days. The total life period varies from 61 to 280 days.

Control: Use of chlorpyrifos 0.02% as a drench at the transplanting stage affords protection.

I. THE RED FLOUR BEETLE *Tribolium castaneum*

It is a cosmopolitan insect which was described and named in 1797. The insect is a small elongate, flat, reddish-brown beetle with antennae ending in abrupt clubs (Fig. 60.16). It is found infesting all stored products like grains, seeds, flour, oilcakes, dry fruits, nuts, etc. and also museum specimens like dry insects, stuffed trophies, etc. In addition to the normal damage it causes to the products, it gives a red taint and an offensive smell to them. It is a highly destructive pest of stored wheat in India.

The female beetle lays about 350 eggs in the stored products like grains, flour, etc. The egg is minute, cylindrical and white. The incubation period lasts for 5 to 12 days. The yellowish white cylindrical grub is covered with fine hairs and becomes fully grown in 27 to 29 days. The pupa is without any covering and emerges as adult within three to seven days. Depending on the weather conditions there may be four to seven generations in one year and a generation may take one to four months.

Control: Seeds of wheat treated with malathion dust at 24 ppm remains effective against infestation up to three months. After treatment, no impairment in the viability of seeds has been noticed up to four months of storage.

Family Meloidae (oil beetles; blister beetles)

The beetles are medium-sized, 1.25 to 2.5 cm long, and conspicuously covered with bright metallic blue, green, black or brown. The head is hypognathous and is joined to the prothorax by a distinct neck. The wings are well developed and loosely cover the body; in some they are vestigial while others are apterous. The fore-coxal cavities open behind and tarsi are five-segmented. The legs are long, appendiculate and usually with serrate tarsal claws. When disturbed, the beetles emit a fluid containing the oil principle, cantharidine, which has irritant properties, through the openings in the apices of the femur. The beetles are usually found on flowers and leaves and cause injury by feeding on them.

The blister beetles undergo a hyper-metamorphosis in their development, which is rather complex. The first instar larva that hatches out from the egg laid in the soil, is active with long legs and is referred to as triungulin. It moves in search of eggs of grasshoppers and bees. In the species that develops in bee's nest, the triungulin climbs upon a flower and from there gets attached to the visiting bee and transported to the nest. The triungulin feeds on the eggs of its host and moults. In the second instar it bears short legs. In the third, fourth and fifth instars it is somewhat scarabaeiform. The sixth instar is coarctate forming a pseudopupa devoid of functional appendages and usually hibernation takes place in this instar. This is followed by small, white and apodous larva of seventh instar, which transforms to a pupa soon.

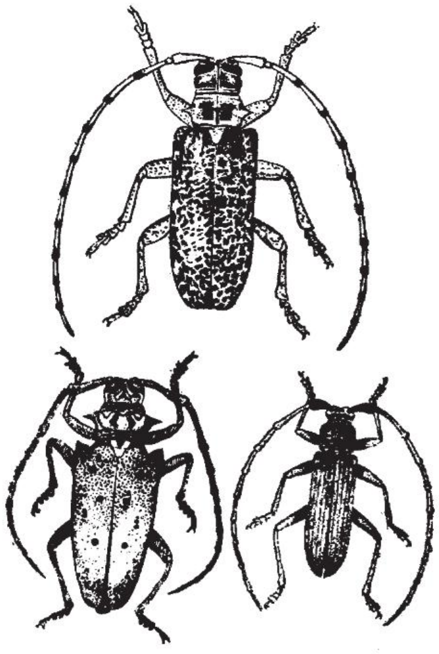
Mylabris phalerata, *M. pustulata* and *M. balteata* are the common species found in India. *Psalydolytta rouxi, Cylindrothorax ruficollis* and *C. tenuicollis* occur on ears of paddy and other millets. *Epicauta hirticornis* contains a higher percentage of cantharidine among Indian meloid beetles.

Superfamily CHRYSOMELOIDEA

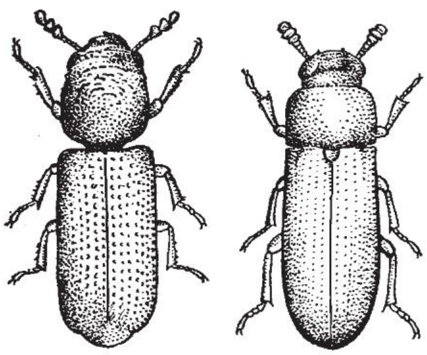
The following are some of the important families which are of economic significance in agriculture.

Family Cerambycidae (long-horned wood-boring beetles)

This is a large family of phytophagous species. The adult beetle is large, cylindrical with long antennae usually at least half as the long as body or often much longer (Fig. 60.15). They are often brightly coloured and others exhibit striking cases of cryptic colouration. In most species the inner margins of eyes are notched and antennae may arise within this notch or just opposite to it. The tibial spurs are well-developed and the tarsi five-segmented, the third segment being bilobed conceals the further segment. Many cerambycids stridulate either by working the hindmargin of prothorax against a specialised striated area at the base of the scutellum or by the hindfemora rubbing against the edges of the elytra. Both types of stridulatory organs may occur in the same insect as in the Hawaiian *Plagithmysus*.



▲ **Fig. 60.15** *Long-horned (top), Coelosterna sp. (bottom right), Stromatium barbatum, (left), Batocera rufomaculata (T.B. Fletcher, 1914)*



▲ **Fig. 60.16** *Tribolium castaneum (right) and Rhyzopertha dominica (left)*

The grubs of Cerambycidae are apodous, elongate, cylindrical and whitish. They bore into woods, stem or roots and thus prove destructive to shade, forest and fruit trees and freshly cut logs. A few girdle vines and oviposit just above the girdled band.

The family Cerambycidae is divided into several subfamilies, some of these being destructive species of economic importance.

Subfamily Lamiinae

Black or mottled grey beetles, over 2.5 cm long, antennae with first segment bearing a scar-like area near its tip and measuring sometimes twice as long as body in male and about as long as body in the female. Usually these infest freshly cut logs and living trees are rarely attacked. This subfamily includes the common genera such as *Anoplophora, Batocera, Coelosterna* (Fig. 60.15), *Monohamus, Sthenias, Linda, Nupsera, Oberea, Apomecyna, Coptops, Olenecamptus,* etc.

1. THE ORANGE TRUNK BORER *Anoplophora versteegi*

The trunk borer is the predominant species responsible for citrus decline on the Darjeeling Hills in West Bengal. It damages 40 to 60 per cent of plants in orange orchards. This is also prevalent in Assam, Bangladesh and Sikkim Hills.

The beetles initially feed on leaves during day time devouring the entire leaf tissue along the midrib, keeping the margin intact, and after sometime they feed on the bark of twigs and branches. The beetles are sluggish. The mated female prefers to oviposit on smooth surfaces of the plant restricting itself mostly to the proximal portion of the trunk, up to a height of 2.5 metres from the ground level. After selecting a suitable spot, it makes a vertical incision of 4 to 12 mm long, turns and then thrusts its ovipositor into the incision wherein an egg is laid. The newly hatched grub feeds on the eggshell and then cuts into the upper sapwood in a horizontal direction. It tunnels through to the middle of the trunk. Then it moves upward tunnelling the central portion and forms the vertical gallery. Before pupation it tunnels at right angles to the vertical gallery and makes an opening, which is plugged with frass. It pupates in a pupal cell in the centre of the trunk. The larval stage lasts on an average for 282 days and the adult emerges from pupa in about 53 days. It is very destructive in *Citrus reticulata.*

2. THE MANGO STEM BORER *Batocera rufomaculata* (Fig. 60.15)

The insect is widely distributed in all mango growing tracts in India. The grubs tunnel into branches and splits the bark, which wilts away in the course of time. It also attacks jack trees, rubber trees, fig trees, eucalyptus, etc.

The adult beetle is about 5 cm long with two pink spots and lateral spines on prothorax and antennae as long as the body. It lays the eggs singly on the bark or in crevices on the tree trunk. The incubation period is one to two weeks. The larval period ranges from three to six months. It pupates in the tunnel itself and the adult emerges in four to six months.

Control: Removal and destruction of affected branches, killing the grubs with a stiff wire or by pouring petrol, paradichlorobenzene crystals, etc. into the bore hole and closing it with mud, and swabbing the branches with chlorpyrifos 0.02 per cent emulsion are some measures suggested for the control of the pest.

3. THE GRAPEVINE STEM GIRDLER *Sthenias grisator*

The bark and the wood of the grapevine are cut using powerful mandibles. Often the base of the vine is neatly girdled by the beetle, which results in drying up of the entire vine. The beetle oviposits underneath the bark of the girdled branch at night and the incubation period is about eight days. The grub tunnels into the wilting branch. The whole life cycle may last for a year.

It is mainly a pest of grapevine. Apart from grapevine it also attacks casuarina, mango, jack, *Morus indica*, croton, cacao, *Bougainvillea, Oleander*, etc.

Control: Swabbing the base of main stem or branches with chlorpyrifos 0.02 % emulsion prevents infestation by the beetle.

4. POINTED GOURD VINE BORER *Apomecyna neglecta* Pasc.

Pointed gourd *Trichosanthes dioca* in South Gujarat is infested by this vine borer. The adults start laying eggs seven to eight days after emergence and live for 37–43 days. Pre-oviposition period is three days. Internodes are preferred for oviposition and eggs are inserted singly 1.0 to 1.5 mm below the bark of vines. The exudates at the point of puncture becomes brownish and hard covering the puncture. A female lays 38–52 eggs. The egg is oval with faint pentagonal markings. The incubation period is five to seven days. The larva is creamy white with brown head and minute setae on the body. There are six larval instars. The larval period varies from 31 to 35 days. Pre pupal period is two to three days. Pupation takes place in the larval tunnel, the pupal period being seven to nine days. Males are black and measure 8.5 mm long whereas females are brown and measure 12 mm long. Female-male ratio is 5:1. The total life cycle ranges from 80 to 98 days.

Subfamily Prioninae

Adults are elongate to oval, somewhat flattened, bright reddish-brown, about 2 cm long and with short antennae not extending beyond the base of the prothorax. The fourth tarsal segment is distinct. The grubs bore into dry dead wood of logs and stumps. The genera included under this subfamily are: *Acanthophorus, Dorysthenes, Macrotoma*, etc.

Subfamily Cerambycinae

A large subfamily comprising of adults of varied sizes and colourations. They are usually large, somewhat flattened and bear very long antennae. The larvae attack all parts of plants. The genera included under this subfamily are: *Chelidonium, Clytocera, Aeolesthes, Aglaophis, Caloclytus, Demonax, Gnatholea, Merionaeda, Neocerambyx, Plocaederus, Stromatium* (Fig. 60.15), *Xylotrechus*, etc.

1. THE ORANGE BORERS *Chloridolum alcamene* (formerly *Chelidonium argentatum*) and *Chelidonium cinctum*

The orange borer *Chloridolum alcamene* is a serious pest of mandarin oranges at Wynaad and is over 2.5 cm long and dark metallic green in colour. *Chelidonium cinctum* is found in parts of Mysore and Coorg and is more greenish, most of them having a prominent yellowish patch on each of the forewings.

Adults emerge soon after heavy showers of rain during June-July and mate. The mated female lays yellowish flattened eggs singly at the branch axils at the terminal ends. The incubation period is 10 to 12 days. The grubs first make a spiral cut, disconnecting the bark from the woody portion which results in wilting of the infested twigs. They feed on the inner core and burrow upwards for a period of two to six weeks. The grubs later reverse the direction, enter the thicker branches below and eventually the main stem. They ramify and feed on the woody portion and their activity is seen by the ejection of appreciable quantities of chewed fibrous material through the holes. The larval period lasts for about ten months. It pupates in the tunnel itself and the pupal period takes three to four weeks. The beetles emerge by about May and wait inside till the rains.

Control: A spray schedule of chlorpyrifos 0.02 % ten times at intervals of three weeks from May-June is suggested. The wilted twigs should be removed during August-September at least four times, and this is a very cheap method. The beetle at its critical stage is removed along with the dried twigs and destroyed. Petrol may be injected into bore holes (5 to 10 ml) and plugged with mud.

2. THE COFFEE WHITE BORER *Xylotrechus quadripes*

This is one of the important pests of coffee in South India. The pest was first noticed as early as 1835 and since then it has been observed in all the coffee growing areas. It is also found in Indo-China, Thailand and Myanmar.

The insect causes severe damage to arabica coffee and rarely attacks robusta coffee. In plantations situated in low elevation and low rainfall areas, and when the north-east monsoon fails, conditions become favourable for the breeding and multiplication of the pest. The larvae are mainly destructive to coffee bushes as they tunnel into the stem for about eight to nine months. Extensive tunnelling in all directions invariably results in death of young plants. Though old plants resist the attack for a few seasons, they are rendered uneconomical in the course of some years. The infested plants present an unhealthy appearance and in cases of severe attack wilting of the branch or whole plant may be observed. In such cases one or more ridges or raised surface on the bark at the point of larval entry into the stem can be located. Apart from coffee it also breeds on *Olea dioica, Ixora coccinia,* etc.

The beetle is dark brown with two white cross bands on elytra and measures about 1.25 cm long. Adult beetles normally emerge during April-May (summer flight) and October-December (autumn-winter flight). The beetles mate and the female oviposits in the crevices and cracks of the bark of the stem. In about two to three weeks an adult lays as many as 50 to 100 eggs. The incubation period is eight to ten days. The larval stage lasts for eight to nine months. Before pupation the larva makes an emergence hole on the surface and pupates inside the stem close to the hole. The adult emerges in 25 to 30 days.

Control: Collection and destruction of affected dry twigs and of adult beetles during April-May and October–December; swabbing the stem with lindane 0.02% emulsion during the flight seasons i.e. once April, and twice during October-November at a month's interval, will be helpful.

3. THE APPLE STEM BORER *Aeolesthes holosericea*

It occurs as a serious pest of apple in certain years in the apple growing areas in the country. It also attacks apricot, peach, pear and plum. The grub whose larval period extends for two to three years, feeds on the inner bark and sap wood of the tree. A hole on the tree with frassy chewed material adhering to bark is seen, the frass also lying on the ground near the stem.

Control: A wick of cotton about 15 cm long may be soaked in a solution of dimethoate 0.03 %, phosphamidon 0.025 %, methyl demeton 0.025 %, dichlorvos 0.1 % or thiometon 0.025 % so as to absorb about 10 ml of the liquid and then introduced into the bore hole with the help of a nail or wire and closed with moist soil. This affords very good control of the pest.

4. THE 'SAL' HEARTWOOD BORER *Hoplocerambyx spinicornis*

This is a very important pest of "sal" (*Shorea robusta*) forests in Central and North India.

In cases of epidemics the whole forest is wiped out. The insect was first observed as a pest of sal in 1899 and since then several epidemics have been recorded in states like Assam, Bihar, H.P., U.P., and M.P. During 1923-28 epidemics 428,000 beetles were killed. During 1997-98 it became an endemic pest of Sal in Madhya Pradesh affecting one sixth of total sal forests spread in six districts covering an area of 300,000 ha and inflicted an estimated loss of Rs.250 crores. During 1997 in M.P. about 15,100,000 beetles were collected and killed.

Generally the beetle breeds in felled and dying trees and healthy trees are attacked in cases of epidemics. The beetles emerge during the first few weeks of monsoon. The pest is on the increase when the rainfall is above normal.

Control: As the beetles are attracted to the fresh sap from the sapwood of "sal," trees which are unsound silviculturally and those which are infested should be felled soon after emergence of beetles begins. These should be cut into logs of 3 to 4 metres in length (girth preferably 1metre or above) and distributed in small heaps in the affected areas. The beetles that collect at the cut ends should be captured and destroyed. This is to be repeated in subsequent years in areas where infestation is severe. Preventive measures include avoiding too dense stocking, particularly in older crops; confining felling of trees to October-March; debarking soon after felling; and removal and destruction of all felling-refuse.

5. THE CANKER-GRUB OF TEAK *Dihammus cervinus*

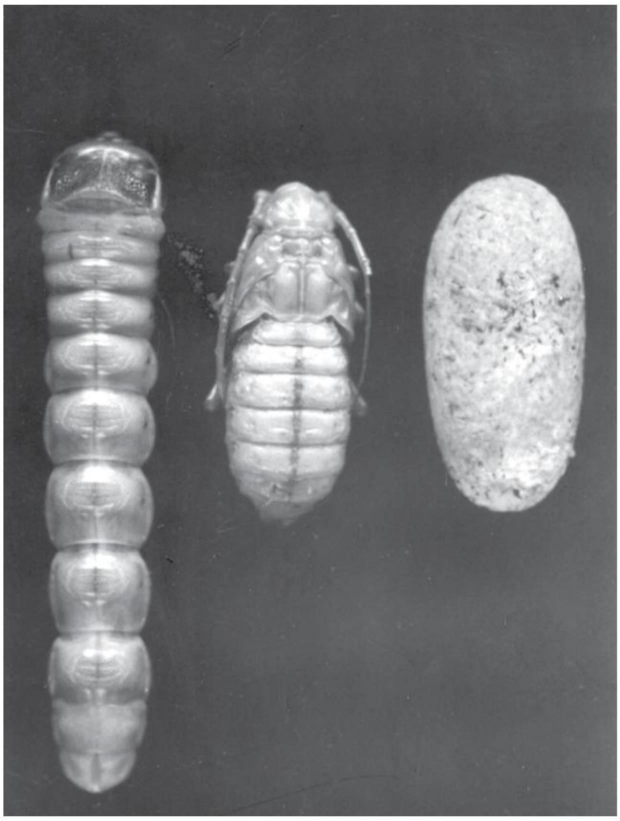
It is a potential pest of living trees in teak and *Gmelina arborea* plantations in northern India and Myanmar. In teak increased formation of wood around the wound takes place due to partial girdling and injury to the cambium, and by the following spring it results in a globular canker twice the diameter of the stem, mostly at a height of 1 metre above ground. The stem gets weakened due to extensive tunnelling by the larva and may break off easily. Teak trees of seven to eight years old or more are not seriously damaged.

As the beetle primarily develops in the roots of the shrub *Clerodendron infortunatum*, removal of the shrub in the plantations is necessary to prevent spread. Infested one to four-year old teak plants should be cut to obtain new stems.

Painting the lower portions of stems of plants with tar, creosote or carbolineum or provision of barriers of wrappings of grass, shrubs, etc. stacked around the stem of plants prevents oviposition by the beetles in May.

THE CASHEW STEM AND ROOT BORER *Plocaederus ferrugineus L.* (Fig. 60.17)

It is a serious pest of cashew in Andhra Pradesh, Karnataka, Kerala, Goa, Maharshtra, Orissa, Tamil Nadu and West Bengal. The damage is inflicted by the grubs, which bore into the stem and roots and feed on soft tissues. The bored holes are plugged with reddish mass of chewed fibre and excreta. A resinous material oozes out from the bore hole. The grown up grub tunnels inside the basal stem portion in a zig-zag manner damaging the cambial tissues and arresting the flow of sap. Discolouration of leaves is the first symptom of attack . Later on, the leaves turn yellowish and drop off. The branches start drying up, the tree gets weakened and ultimately dies. Infestation varies from 4-10 % in the affacted crop.



▲ **Fig. 60.17** *Cashew borer — Left to right Larva, pupa and cocoon (courtesy: V. Ambethgar)*

The adult (Fig. 60.18) is a medium-sized reddish-brown beetle measuring 30–40 mm long. The head and prothorax are dark brown. The adults are sluggish on emergence. Mating commences the next day and the pre-oviposition period ranges from five to ten days. The female lays the dull-white ovoid eggs, measuring about 3 mm, singly in the crevices of the bark. The incubation period is seven to ten days. The newly hatched larva is dull white with a brownish head and broad prothorax. They feed on the soft tissues of the bark and stem and reach a length of about 7 cm in a larval period of 140–150 days. The grub constructs an oval chamber inside the stem and pupates. The adult emerges in 100–160 days. The life cycle is completed in 9–10 months.

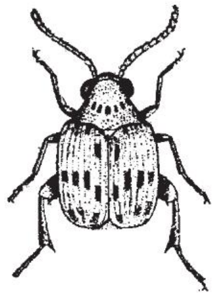
▲ **Fig. 60.18** *Adult of Plocaederus ferrugineus (ibid)*

Besides cashew it also attacks silk cotton tree, sal tree, rubber, jack, mango, fig, guava, pomegranate, apple, walnut, etc.
The grubs and pupae are susceptible to *Metarrhizium anisopliae* and 30 per cent mortality of grubs has been observed.

Control: Removal and destruction of infested dead branches and trees is suggested. In the early stage of attack as far as possible the grubs should be extracted and killed. Swabbing the bark with chlorpyrifos 0.02% emulsion is suggested. Stem injection of monocrotophos or root feeding at 20 ml/tree has been found promising.

Family Bruchidae (seed beetles) (Fig. 60.19)

Small, short, stout-bodied beetles covered by setae or scale and are usually dull greyish or brownish in colour. The elytra are short and do not cover the tip of abdomen. The head is hypognathous, and produced into a broad short snout anteriorly. Antennae are usually clavate, serrate or pectinate. Body is somewhat narrowed anteriorly. The elytra are smooth, striate and covered with scales. The tarsi are five-segmented ending in claws hooked at base, the femora often swollen and dentate.



▲ **Fig. 60.19** *Callosobruchus sp. (T.B. Fletcher, 1914)*

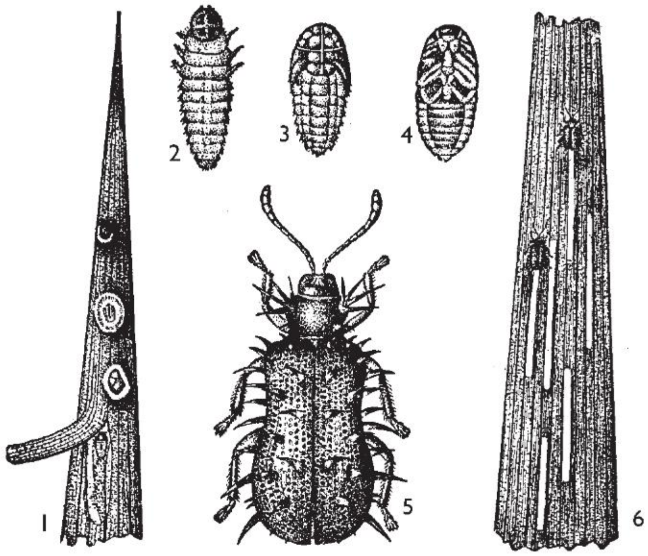
The larvae feed exclusively on seeds of legumes and they undergo hyper-metamorphosis. The carabaoid type first instar larva possesses well-developed legs and toothed thoracic plates with the help of which it gains entry into the seed. After the first moult it becomes eruciform and often more or less apodous.

Collosobruchus chinensis infests the seeds of different pulses such as redgram, Bengal gram, lab lab, green gram, cowpea, etc., in storage. It also causes damage to seeds in pods of redgram in the field. *C. maculatus* also infests seeds of Bengal gram, cowpea, greengram, peas, etc. in storage. *Caryedon gonagra* feeds in pods of tamarind, *Acacia pinnata, Bauhinia malabarica, B. racemosa, Cassia auriculata, C. fistula*, etc.

Family Hispidae (leaf-mining beetles)

Small elongate beetles, 4 to 7 mm in length, with the head free and not retracted beneath prothorax, antennae are usually short and not inserted on frontal prominences; mouth is inferior; tibial spurs are absent, body is narrow anteriorly and broad and truncate posteriorly, and elytra with ridges and spines. The larvae are mostly leaf-miners and also feed by scraping leaf tissue. The genera included in the family are *Dicladispa, Hispa, Asmangulia, Rhadinosa, Trichispa, Dorcathispa, Polygonia, Leptispa, Platypria, Onchocephala, Dactylispa, Oediopalpa* and *Callispa.* In India, the rice hispa *Dicladispa armigera* is a well-known pest. The other common insects noticed are : *Leptispa pygmoea* on paddy, *Onchocephala tuberculata* on sweet potato, *Asmangulia cuspidata* on sugarcane and *Callispa* sp. on coconut.

1. THE RICE HISPA *Dicladispa armigera* (Fig. 60.20)



▲ **Fig. 60.20** *Dicladispa armigera: 1. Eggs and larva on leaf tip, 2. Grub, 3 & 4. Pupa, 5. Adult, 6. Beetles feeding on leaf (T. V. R. Ayyar, Handbook of Economic Entomology for South India, 1940)*

The insect is known to occur in Sri Lanka, parts of China, Cambodia, India, Laos, Nepal to Indonesia, New Guinea, the Philippines and Vietnam. In India, especially in Andhra Pradesh, West Bengal and Bihar, the infestation often assumes serious proportions on young paddy crop. The damage varies from 25 to 65 per cent. The beetle itself feeds on the green matter of the tender leaves producing the characteristic narrow white lines on them. The grubs mine into the leaf tissue and eat up the leaf contents; the presence of these grubs in the leaf tissue is indicated by the peculiar blister spots towards the tip of the leaves. In cases of severe attack the leaves turn brown and wither away presenting a sickly white appearance.

The adult beetle is steel blue to black in colour, 4.5 to 5 mm long and has a short single spine on elytra and paired four pronged and single spines on thorax. It lays its eggs inside minute slits made on tender leaves, generally towards the leaf tip. A female beetle on an average lays 55 eggs and the incubation period is four to five days. The small, yellowish, flattened grubs feed on the leaf tissue inside the leaf mine for 7 to 12 days. It pupates in the mine itself and emerges in three to five days. There may be about six generations in one year.

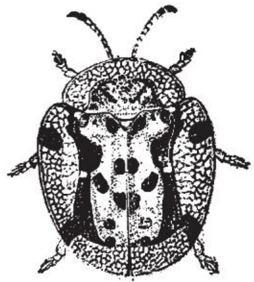
It also attacks sugarcane and grasses.

Control: The grubs of the beetle are parasitised by *Bracon* sp. Hand-netting and destruction of adults may be done. Clipping of the leaf tips enables removal of eggs and other stages of the beetle, Spray application of methyl demeton, parathion, phosphamidon, fenthion, carbaryl and endosulfan 0.05 % or diazinon and fenitrothion 0.07 % is effective in controlling the pest. Quinalphos 1.5 % dusting gives relief.

Family Cassididae (tortoise beetles)

Broadly oval or circular beetles with head concealed under prothorax and body and elytra broadly widened. The mouth is inferior in position. Antennae are short and not inserted on frontal prominences. The beetles are 5 to 6 mm in length, brightly coloured with markings. The somewhat flattened, elongate to oval larvae are spiny and bear at the posterior end, a forked process which is usually bent upward and forward over the body. The cast skins and excrement are attached to this process, which form a shield like covering over the body. Both larvae and adults are phytophagous, scraping and biting holes on leaves of a wide variety of plants.

Aspidomorpha miliaris (Fig. 60.21), *Chirida bipunctata* and *Metriona circumdata* infest sweet potato and other *Ipomoea* spp. *Oocassida obscura* feeds on *Zizyphus*. *Silana farinosa* damages *Murraya koenigi* leaves in South India. *Cassida exilis* attacks amaranthus.



▲ **Fig. 60.21** *Aspidomorpha miliaris (T.B. Fletcher, 1914)*

Family Clytridae

These are small, robust, somewhat cylindrical beetles with antennae widely separated at base and pygidium exposed. The mouth is anteriorly situated. The members of this family are characterised by short and serrate antennae, prominent eyes, prothorax without grooves, non-tuberculate elytra and absence of teeth or hindfemora. *Clytra orientalis* and *Clytrasoma conformis* occur in India.

Family Cryptocephalidae

This family is closely related to Clytridae but differs from the latter in having a long usually filiform antennae. This includes species of the genus *Cryptocephalus*.

Family Donaciidae (long-horned leaf beetles)

The beetles are elongate, slender, metallic black, greenish or coppery with long antennae. They are characterised by antennae widely separated at base but not separated by the entire front of head, head produced and with prominent eyes, prothorax laterally rounded and narrow prosternum and pygidium not exposed beyond elytra.

Donacia aeraria in Japan, and *D. lenzi* and *D. provosti* in Korea attack rice roots in their larval stage.

Family Sagridae

This family is closely related to Donaciidae but is distinct from Donaciiade in having the antennae separated by the entire front of head.

Sagra nigrita infests *Lablab niger* in South India.

Family Chrysomelidae

The beetles are oval, convex, brightly coloured and measure 3.5 to 12 mm long. The antennae are widely separated at base, head not produced, eyes not prominent, prothorax laterally margined, prosternum broad and pygidium not exposed beyond elytra. The third tarsal segment is not bilobed and the forecoxae are transverse.

This family includes the genera *Leptinotarsa, Chrysomela, Flagiodera, Maecolaspis,* etc.

Family Alticidae (flea beetles)

These are small jumping beetles, black, blue, greenish or brownish in colour. Some have light markings. Though it closely resembles Chrysomelidae this group is characterised by closely approximated antennae, globose forecoxae, deeply bilobed third tarsal segment, grooved tibiae and swollen hindfemora. A number of flea beetles are known to be major pests. *Longitarsus belgaumensis* more on sunnhemp, *L. nigripennis* on pepper, *Phyllotreta downsei* on cruciferous vegetables and *Chaetocnema pusaensis* on millets are well known pests in India. The steel blue beetle *Altica cyanea*, often found in large numbers on rice, feed on the weed plant *Ammania* in rice fields. It also breeds on the foliage of singhara (*Trapa bispinosa*) crop in Delhi.

1. THE SUNNHEMP FLEA BEETLE *Longitarsus belgaumensis* Jac.

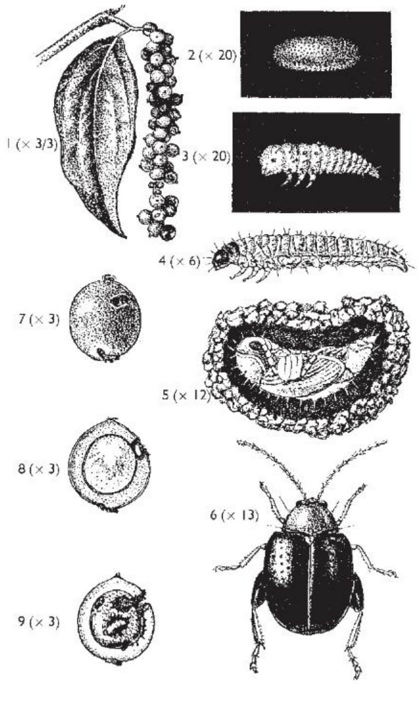
The flea beetle is small, light yellowish brown with enlarged hindfemora and measures 2.45 to 2.68 mm long. It feeds on the cotyledonary leaves as well as the upper leaves of plants. It is active during June–July and October–December. The female lays orange coloured sculptured cylindrical eggs (0.50 mm long and 0.22 mm broad) in the soil. The incubation period is seven to eight days. The first instar creamy white grub mines into tender growing roots and cotyledon of germinated seeds of sunnhemp (*Crotalaria juncea*) plants. Fully grown grub is 3.8 mm long. It pupates in an earthen cocoon in the soil. The pupa is creamy white and of exarate type. The total life cycle takes 23 to 34 days, the egg, larval and pupal periods being 6 to 9,12 to 13 and 10 to 15 days respectively.

2. THE POLLU BEETLE OR PEPPER FLEA BEETLE *Longitarsus nigripennis* (Fig. 60.22)

It is a serious pest of black pepper (*Piper nigrum*) along the West Coast of India. The pale yellowish grubs bore into ripening berries, feed on the seeds and make them hollow. It causes 30 to 40 per cent loss in yield of pepper crop.

The adult beetle is of a shining yellow blue colour and 3mm in length. It thrusts the egg singly underneath the rind of the green tender berry. Only one egg is laid in a berry. The incubation period is seven to ten days. A grub damages two to three berries. The grub feeds for 40 to 45 days, drops to the ground and pupates in an earthen cell. The adult emerges in a week.

Control: Two rounds of spray application of lindane 0.1 % at an interval of 30 to 40 days, with the first application commencing in July-August, at 3 litres of spray solution per vine affords protection.

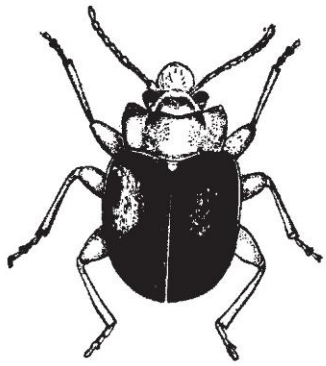


▲ **Fig. 60.22** *Longitarsus nigripennis. 1. Attacked pepper spike, 2. Egg, 3 & 4. Grub, 5. Pupa, 6. Adult, 7-9. Damagae in berry (T. V. R. Ayyar, 1940)*

Raking the soil and exposing the pupating larvae and pupae and incorporation of lindane or chlorpyrifos into the soil may be useful.

Family Galerucidae (cucumber beetles)

These are soft-bodied insects, 2.5 to 11 mm in length; yellowish with dark spots or stripes and characterised by closely approximated antennae, deeply bilobed third tarsal segment, globose forecoxae, tibiae not grooved and hindfemora not swollen. The larvae feed on roots and underground stems of cucurbitaceous plants. Some feed on leaves of millets by scraping the leaf tissue. The adults of the cucumber beetle *Acalymma vittata* is known to be a vector of cucurbit wilt in the USA. This family includes genera like *Aulacophora, Monolepta, Lema, Diabrotica, Hallirhotius, Hyperacantha, Galerucella* (Fig. 60.23), *Galerucida*, etc.



▲ **Fig. 60.23** *Galerucella sp.*

In India *Galerucella birmanica* is a pest of *singhara (Trapa bispinosa)* crop in and around Delhi. In Jammu-Kashmir *G. placida* has been reported to feed on polygonaceous medicinal plants. The beetles *Aulacophora cincta, A. lewsii* and *Raphidopalpa foveicollis* are very common on cucurbitaceous plants. *Oulema downsei* is destructive to millets.

1. The Pumpkin Beetles *Aulacophora cincta* (grey with black border), *Aulacophora lewsii* (blue beetle) and *Raphidopalpa foveicollis* (red beetle).

The beetles make holes on leaves of pumpkin, melons, etc. and also feed on flowers. The grubs remain in the soil and feed on roots, stems and fruits.

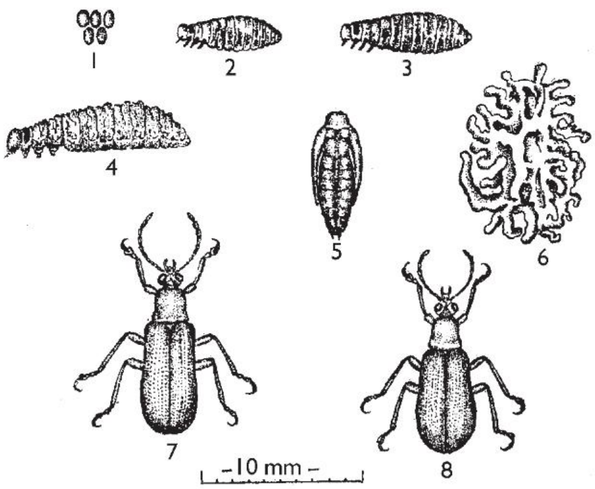
A female beetle lays 150 to 300 brownish elongate eggs in the soil. The incubation period is five to eight days. The whitish grub with brown head bores into roots and feeds on them. The vines and fruits which rest on the ground are also bored and damaged. The larval period lasts for 13 to 25 days. It pupates in the soil up to a depth of 25 cm. Adult emerges in 7 to 17 days. Five to eight generations are noticed in one year. It is active from March to October and hibernates during the cold season as adult.

It has been shown that *R. foveicollis* prefers pumpkin *(Cucurbita maxima)* and *A. cincta* prefers sponge gourd *(Luffa cylindrica)* and both the species do not feed on *Momordica charantia*. In general, both the species feed on *Cucurbita maxima, C. pepo, Cucumis melo* var. *utilissimus, C. melo, C. sativus, Citrullus lanatus, C. vulgaris* var. *fistulosus, Luffa cylindrica,* *L. acutangula* and *Trichosanthes anguina.* The beetle *R. .foveicollis* in addition feeds on *Benincasa hispida* and *Lagenaria vulgaris* also.

Control: Spray application of methyl parathion 0.025 % or DDVP at 0.04 % controls the adults.

2. THE YAM BLUE BEETLE *Lema lacordairei* (Fig. 60.24)

It has been reported as a pest of *Dioscorea alata,* an edible tuber of Kerala, both the adults and grubs feeding on leaves. The beetles with shining blue elytra and yellowish body measures about 8 mm. The longevity is 70–75 days in the case of male and 90–95 days in female. Mating takes place at night and females start laying eggs 7–10 days after mating. A female lays 20–25 eggs during an oviposition period of 30–40 days. The yellowish smooth cylindrical eggs are laid loose on the lower surface of leaves, on the vines or on the supports of vines. The incubation period is two to three days. The grub stage passes through three instars. The grub is yellowish with brown head and black prothoracic shield and legs, and is charaterised by a small head, narrow thorax and a disproportionately thick and fleshy abdomen concealed by coverings of its excrements carried dorsally. The prepupal period is three days during which the grub ceases to feed and constructs a cocoon with a whitish frothy secretion from its mouth on the leaf or in the soil. The pupa is yellowish brown and measures 6.5 to 7.0 mm long and the pupal period lasts for seven to nine days.



▲ **Fig. 60.24** *Life stages of Lema lacordairei. 1. Eggs, 2-4. Grubs, 5. Pupa,6. Cocoon, 7. Adult male, 8. Adult female (A. Visalakshi and M.R.G.K. Nair, Entomon)*

3. THE SINGHARA BEETLE *Galerucella birmanica* Jacoby

This is a serious pest of *Trapa bispinosa* in India. The adult is reddish brown with an elongated body and a blunt abdominal tip. The adult matures sexually within nine days of its emergence. The longevity of female and male varies being 28 and 17 days respectively. A female lays about 79 eggs in clusters on the upper surface of leaves in 12 days. The egg, larval and pupal periods being 6, 14 and 4 days, respectively. The life cycle is prolonged to 44 days in December whereas it is 15-16 days in September. There are twelve generations in a year.

Family Eumolpidae

These beetles are usually oblong, convex, either metallic or yellowish with spots. The beetles are characterised by a prothorax which is narrower than elytra and legs not compressed. The genera included under the family are: *Colaspis, Scelodonta, Eryxia, Adoxus, Chrysochus, Colasposoma, Bromiodes, Eurypelta, Nodostoma, Pachynephorus* etc. In India *Scelodonta strigicollis* is a well known pest of grapevine. *Nodostoma pubicolle* and *Colasposoma metallicum* are the other common species.

1. THE GRAPEVINE FLEA BEETLE *Scelodonta strigicollis*

The adult beetle is small, shining reddish-brown with six black spots. The adult beetles are very destructive as they nibble and eat away fresh leaf buds which appear after pruning on vines. The grubs on the other hand are not very harmful though they feed on the cortical portion of roots. It has been reported to cause 11 to 31 per cent damage in the vineyards.

The female beetle lays eggs in the soil or in the bark in groups or singly. The incubation period is four days. The grubs remain in the soil up to depths of 15 cm and feed on roots and pupate in earthen cells. The adult beetles emerge in a week. The total life cycle occupies about two months.

After pruning, when fresh buds are blooming, spraying the vines, with chlorpyrifos 0.02% or lindane 0.02% or carbaryl 0.1% is effective. However, depending on severity of infestation application must be repeated.

2. THE CARDAMON ROOT GRUB *Basilepta fulvicorne* Jacoby

It is a major pest of cardamon (*Elleteria cardamomum*) in India since early 1980s causing damage to roots. Drenching the clumps with chlorpyrifos 0.04% emulsion at 5 litres/clump affords protection.

Superfamily CURCULIONOIDEA

These include a large group of insects which are mostly phytophagous and hence are of considerable agricultural importance. In most species, excepting Scolytidae and Platypodidae, the head is prolonged into a beak or snout. The gula is not developed and the gular sutures are lacking or nearly always confluent. Excepting Anthribidae the others lack prosternal sutures. The tarsi are four-segmented and in some five-segmented. The following are some of the important families.

Family Anthribidae (fungus weevils)

These insects are found in abundance in Indo-Malaysian region. They are chiefly found on dead branches, beneath loose bark and on fungi; *Brachytarsus* is predaceous on scales. The larvae live on fungi, some on seeds and a few bore into dead wood.

The insects are small to minute, 0.5 to 11 mm in length, possess short and broad beak and non-geniculate antennae which are short in some species with a three-segmented club while in others, the antennae are long and slender. The tarsi are four-segmented. *Zygenodes* is a form with stalked compound eyes.

The coffee bean weevil *Araecerus fasciculatus* is an important pest of seeds, berries and dried fruits. In India it infests coffee, areca nut and *Argyra canata.* The weevil attacks arabica and robusta coffee berries in the field as well as dry beans in storage. The infested berries are blackened and shrunk and bear circular holes of 0.5 to 1.0 mm. However, the damage is severe mostly in stored beans especially during September due to the high moisture content absorbed by the beans during monsoon. It takes 45 to 60 days to complete its life cycle in coffee beans. For stored beans, fumigation with ethylene dibromide and methyl bromide (1:1) has been suggested and this does not affect the quality and detectable residues are within the tolerance limit of 50 ppm. Application of lindane on the exterior of stock has been suggested as a prophylactic measure with a view to prevent cross-infestation.

Family Apionidae

This is a small group of beetles with non-geniculate antennae. The insects develop in seeds and stems or roots of plants. The common genera included are *Apion* and *Cylas.*

The important species met with in India are the sweet potato weevil, *Cylas formicarius, Apion ampulum* breeding in green gram, cashew, etc. and *Apion corchori* infesting jute in northern India.

1. THE SWEET POTATO WEEVIL *Cylas formicarius*

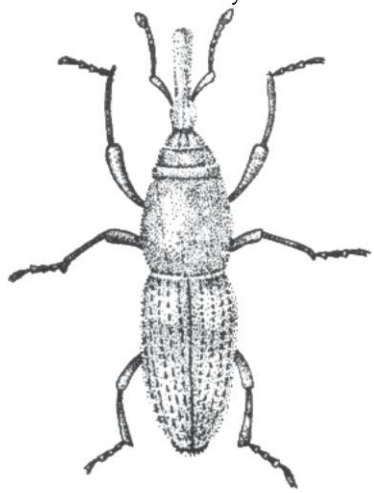
The insect (Fig. 60.25) has a wide distribution and is an important pest of sweet potato in India.

The grubs bore into tender vines and stems, and tubers making them unfit for use. Considerable damage (up to 70 %) is caused by the pest. Adults attack the leaves, vines and tubers. It is a pest both in the field and during storage.

The adult beetle is ant-like, slender, shiny black with thorax and legs being red. The snout is long with non-geniculate antennae. The pre-oviposition period ranges from 4 to 11 days. The female lays eggs in cavities on vines or tubers and covers them. A female lays 97 to 216 eggs and the oviposition period ranges from 51 to 102 days. The incubation period is six to seven days. The grub is apodous and whitish with a brown head. The larval period varies from 21 to 26 days. It pupates inside the burrow itself after a prepupal stage of one or two days. The adult emerges in 8 to 11 days. The total life cycle occupies 36 to 43 days. The adult longevity is 69 to 108 days in female and 91 to 130 days in male.

Apart from sweet potato *(Ipomoea batatas)*, it also infests *lpomoea lateralis, I. learii, I. purpurea, I. prescaprae, I. trifida, I. trichocarpa, I. paundurata, I. palmata, I. sepiaria, Calonyction aculeata* and *Jaguemontia tamnifolia*.

Control: Vines free from infestation should be used as planting material and infested materials should be destroyed. Periodical hoeing closes the cracks in fields and minimises damage. Spray application of fenthion 0.01% or monocrotophos 0.05% or carbaryl 0.1% three rounds at interval of three weeks commencing 45 days from planting may be effective. Use of pheromone traps has been found successful in minimising damage.



▲ **Fig. 60.25** *Cylas formicarius (T.B. Fletcher, 1914)*

2. THE JUTE STEM WEEVIL *Apion corchori*

The insect is distributed in Assam, Bihar, Orissa, Bengal, Andhra and Tamil Nadu.

It is an important pest of jute in India. When the adult bores the stem for laying eggs it pierces the epidermis, cortex, starch sheath and phloem and often also the cambium which results in checking the development of fibres and wood at the site of injury. The maximum damage is inflicted by the grubs which tunnel into the pith damaging the fibre. A swelling at the seat of injury indicates infestation by the pest. Among the cultivated types *Corchorus olitorius* is less susceptible than *C. capsularis*.

The adult is a minute weevil measuring 1.8 mm long with a conspicuous, curved snout. It is dull black or dark brown and clothed with sparse whitish setae throughout the body. The pre-oviposition period is three to nine days. The female digs a small hole and deposits the egg singly. The eggs are laid singly in the stem near the base of the petiole, not very far from the apex. Occasionally it may oviposit in seed pods or petiole. A female lays as high as 675 eggs during an oviposition period of 124 days. The incubation period is three to five days. The grub is light yellowish with light brown head and measures 2.85 mm long. The larval stage lasts for 8 to 18 days. It pupates inside the bore hole and the adult emerges in four days. The whole life cycle from egg to adult takes 15 to 25 days. The winter is passed as adult.

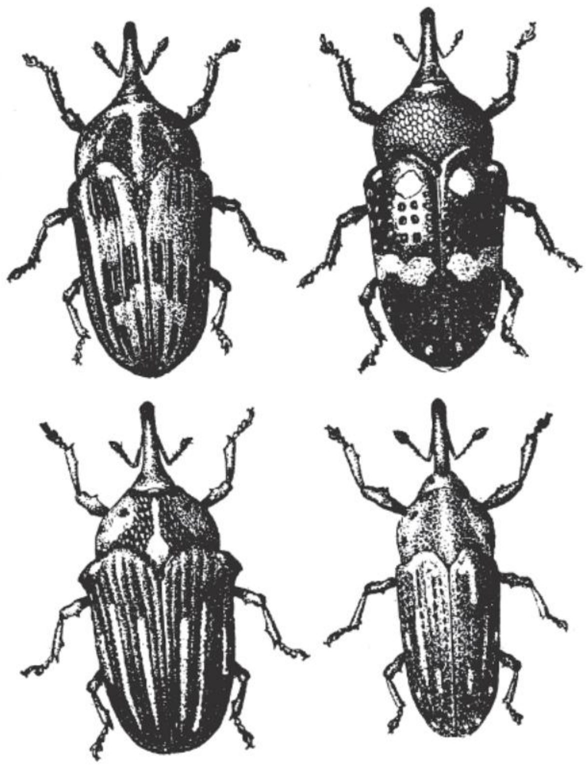
The insect attacks *Corchorus acutangulus, C. frilocularis, C. fascicularis. C. olitorius, C. capsularis* and *Triumfetta rhomboidea.*

Family Curculionidae (weevils)

The adult beetles are minute or large, 0.3 to 5 cm in length, and coloured dull brown, grey, black and a few green. The head is more or less prolonged into a snout, which varies considerably in size, shape and length and bears the mouthparts at the tip. A labrum is usually wanting. The eyes are well developed. The antennae are geniculate and clavate and arise from about the midlength of the snout. In many the body is clothed with scales. When disturbed the adult beetles fall to the ground and remain motionless.

In *Brachyrhinus* parthenogenesis is frequent. The adult females oviposit in leaves, leaf-rolls, flower buds, stems, pods, fruits and nuts or in the soil. The apodous grubs are phytophagous. They feed in leaf mines on rolled leaves, leaf and flower buds, stems, pods, nuts, fruits and stored seeds or on roots of plants. Some cause galls on the stems of plants. The entire life cycle may be completed on the different parts of plants above ground or in the soil; in others the pupa remains in the soil. The grubs pupate inside the plant parts in cocoons of plant fibres or silk or in the soil in earthen cells.

A large number of species of weevils are potential pests of crops in the field and of grains such as wheat, sorghum and rice in storage. The common species noticed in India are: *Episomus lacerta, Myllocerus discolor, M. viridanus, M. subfasciatus, M. undecimpustulatus maculosus, Atactogaster finitimus, Hypolixus truncatulus, Paramecops farinosa, Apoderus* *tranquebaricus, Alcidodes bubo, A. affaber, A. collaris,* (Fig. 60.26), *Indozocladius asperulus, Rhynchaenus mangiferae, Hypera postica, Pempherulus affinis, Baris trichosanthis, Rhynchophorus ferrugineus, Amorphoidea arcuata, Cosmopolites sordidus, Ochyromera artocarpi, Calandra stigmaticollis, C. oryzae, Odoiporus longicollis*, etc.

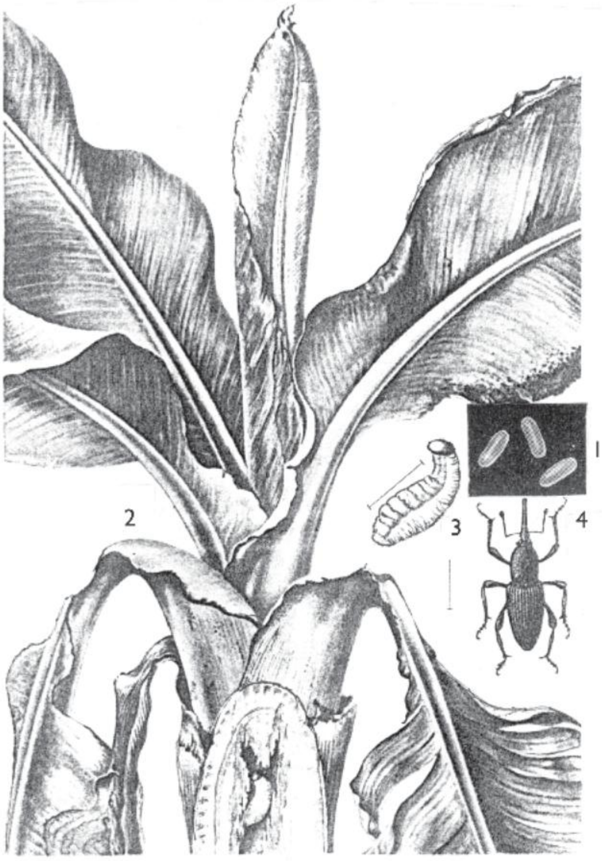


▲ **Fig. 60.26** *Top right Alcidodes collaris; left A. pictus, bottom right A. bubo: left A. fabricii*

The following are some important pests of crops in India.

1. THE BANANA RHIZOME WEEVIL C*osmopolites sordidus* Germ (Fig. 60.27)

It is a serious pest of bananas in most banana growing areas of the world. Adults feed on the plant tissues but cause relatively little damage. However, the grubs which bore into the rhizomes cause death of plants.



▲ **Fig. 60.27** *Cosmopolites sordidus. 1. Eggs, 2. Damage (note dying heart leaf), 3. Larva, 4. Adult (Bayer A.G., 1968; modified)*

The adult is black, hard-shelled with a long snout and measures 1.25 cm long. It oviposits in the rootstock or leaf sheath just above ground level. The egg is white, sausage-shaped and measures 2 mm long and is laid singly. The incubation period may vary from 4 to 30 days depending on weather. The grub immediately on hatching from the egg tunnels moves into the plant tissue and feeds on the tissue contents. The larval period may vary from 21 to several months depending on weather. The full grown grub is stout, apodous with a brown head and measures 1.25 cm long. Pupation occurs within the affected rhizome below the ground level. The pupal stage lasts for eight days.

Control: The infested plants should be dug out and destroyed. Only healthy suckers should be selected for planting. Drenching with chlorpyrifos 0.1% emulsion in the soil before planting may afford some relief.

2. THE MANGO LEAF FLEA WEEVIL *Rhynchaenus mangiferae*

It is widely distributed in South India and is a minor pest of mango. The adults feed on the leaf tissue from the tip portion of tender leaves, which turn brown and dry up. The leaves curl up and get distorted. The larvae mine into leaves, which widen into blotch mines. It damages mango leaves during February-June.

The adult weevil is small, pale reddish-brown, 2 mm long with dark-brown elytra and a short beak. They possess enlarged hindfemora and jump like flea-beetles and hence is called "flea weevil." The adult female excavates a small longitudinal slit in the leaf tissue on the undersurface of leaf and deposits eggs. The incubation period is three days. The grubs mine in between the epidermal layers and become full grown in four to five days. It pupates in the blotch mines and emerges as adult in three to four days. The total life cycle lasts for 10 to 12 days.

3. THE LUCERNE WEEVIL *Hypera postica*

The insect is distributed in Europe, the USA and Asia. In India it is known from Punjab, Delhi, Rajasthan, Uttar Pradesh and Madhya Pradesh.

The insect is a serious pest of the fodder crop lucerne (*Medicago sativa*) in India. The adult weevils are nocturnal and they feed on leaves causing stunting of plants. The grubs feed on the growing leaf buds and leaves. The grubs remain curled while feeding and resting. In severe attacks, as many as 20 to 25 grubs are noticed in a single plant.

The aestivating adult weevils make their appearance in lucerne field in December and feed on leaves. It is active from December to April. They mate and the mated female makes holes in tender shoots. It deposits the round yellowish eggs singly in each hole and pushes them into the stem with the help of the rostrum. A maxium of 41 eggs are laid in a stem. The grubs become fully grown in 20 to 35 days and spin cocoons in between two leaves or on a single leaf but occasionally on stem and pupate. The cocoons may be formed on weed plants also. The adult emerges in 10 to 15 days. The total life cycle takes 32 to 50 days. There is only one generation in a year.

The lucerne weevil also feeds on *Melilotus alba.*

Though a large number of insects have been observed to be parasitic on the different stages of weevil, an ichneumonid *Bathyplectes curculionis* has been found to be an important parasite of the grubs of the pest.

4. THE COTTON STEM WEEVIL *Pempherulus affinis*

The insect is known from India, Myanmar, Thailand, and the Philippines. In India it occurs in Tamil Nadu, Andhra Pradesh, Karnataka, Kerala, Bihar, Orissa, Rajasthan, Uttar Pradesh, Gujarat and Assam.

The insect is known to be a serious pest of Cambodia cotton in South India, especially on summer crop. It causes mortality of plants, up to 25 %, especially during the early stages of growth. The infestation starts on 12 to 15 day old cotton plants and four to five month old plants survive attack. A high proportion of attacked plants withstand the injury either by repair and development of a woody gall at the infested site or by exuding a gummy substance and killing the grub.

The adults generally feed on bark of plants and they mate soon after emergence. The adult female lays the eggs singly in the cavity gnawed in hypocotyl region just above the ground level. A female lays up to 121 eggs, average being 50, during an oviposition period of 60 to 80 days and on a stem seven to eight eggs may be laid. The egg is oval or globular, milky white and smooth and the incubation period is six to ten days. The grub cuts through the medullary rays and tunnels round the stem along the cambium taking a slanting downward course and feeding on the soft portion. The grub stage lasts for 35 to 57 days. It pupates inside the stem in a specially prepared chamber and emerges as adult in 25 to 30 days. It passes three generations from October to April.

The weevil breeds on *Abelmoschus esculentus, Abutilon glaucum, A. hirtum, A. indicum, Abelmoschus esculentus, Althaea rosea, Corchorus acutangulus, C. olitorius, C. trilocularis, Hibiscus cannabinus, H. ficulneus, H.surattensis, H. vitifolius, Malvastrum coromandelianum, Melochia corchorifera, Pavonia zeylanica, Sida acuta, S. cordifolia, S. glutinosa, S. rhombifolia, S. rhomboidea, S. spinosa, Thespesia* spp., *Triumfetta rhomboidea, Urena lobata* and *U. sinuata*. The most favoured host is *Triumfetta rhomboidea.*

The hymenopterous insects *Euderus pempheriphilla, Aplastomorpha calandrae, Eupelmus urozonus, Eupelmella pedatoria, Aximoposis, Eurytoma* sp., *Entadon pempheridis, Dinarmus coimbatorensis, Bruchocida orientalis* (chalcids), *Spathius critolaus, S. labadcus, Microbracon* sp., *Rhaconotus cleanthes* and *R. menippus* (braconids) are parasitic on the grubs of the weevil. Though a large number of parasites have been observed, the parasitism in cotton fields is apparently too low to exercise any adequate control.

Control: Removal and destruction of attacked plants should be carried out. Application of sprays of chlorpyrifos 0.02% at 15-day intervals commencing three weeks after sowing minimises damage.

5. THE RED PALM WEEVIL *Rhynchophorus ferrugineus*

The insect is prevalent in all coconut growing areas. It lives generally in living palms and often its attack is fatal. The early indications of attack is the presence of a few small holes in the stem from which pieces of chewed fibres protrude and a thick brown liquid oozes out. In the advanced stage the central shoot dries up and the inner part of the stem becomes a seething mass of grubs, cocoons and adult weevils. The crown region is attacked in grown up palms. Higher incidence of the beetle has been correlated with leaf rot disease.

The adult weevil is reddish-brown with six spots on the thorax and a conspicuous snout which in the male has a tuft of hairs. It scoops out small holes and oviposits on palms of up to seven years of age while on grown up trees it normally lays the eggs in the wounds, cuts or other injuries caused by man, rhinoceros beetle, etc. As many as 276 eggs are laid by a female. The egg is white, oval and hatches in two to five days. The apodous, light yellowish grub with a red head becomes fully grown in 36 to 78 days and pupates inside the trunk in fibrous cocoon. The adult emerges in 12 to 33 days. In a trunk 40 to 45 beetles can be noticed.

Control: Infested dying palms and dead palms should be cut and burnt. The infested portion should be scooped out and dressed with tar. A solution of 1 per cent Pyracone E (a mixture of pyrethrin 1 part and piperonyl butoxide 10 parts) i.e. 1 part in 100 litres of water, or 1 per cent carbaryl or monocrotophos 36SC 5 ml + DDVP 76SC 5 ml when injected through a hole on the crown at 1000 to 1500 ml per tree brings about appreciable control. Use of pheromone traps has been also found promising in trapping the adults. *Cheliosoches morio* (Forficulidae : Dermaptera) is predaceous on eggs and early instar grubs. Pheromone with traps are commercially available.

6. THE MALVACEOUS STEM WEEVIL *Alcidodes affaber*

The insect is a common pest on Malvaceous plants in India. The adults feed on leaf buds, petioles and tender terminal portions. However, serious damage is inflicted only by the grubs boring into stems and petioles and causing gall-like swellings. Frass is thrown out through holes made on stems. The infested plants become stunted and their flower and fruit production get affected considerably. A single plant may harbour as many as 12 grubs. The insect is active from September to December.

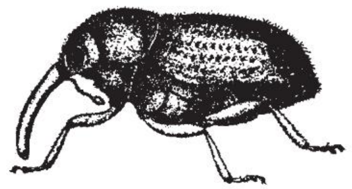
The weevils mate three to six days after emergence and the pre-oviposition period ranges from 8 to 11 days. The adult female excavates on leaf petioles and stems and lays the eggs singly. A female lays about 45 eggs in about 34 days. The grub is creamy yellow and apodous and pupates inside the larval burrow. The total life cycle lasts for 72 to 80 days, the egg, larval and pupal periods being 6 to 7, 55 to 62 and 10 to 12 days respectively. The adult longevity ranges from 6 to 43 days in female and 8 to 32 days in male.

It attacks cotton, *Abelmoschus esculentus, Hibiscus cannabinus, H. mutabilis, H. ficulneus, Urena lobata, U. sinuta, Bombax malabaricum, Kydia calcyina, Althaea rosea, Ficus bengalensis* and *Eriodendron anfractuosum.* The grubs are parasitised by *Aphrastobracon alcidophagus* (braconid) and *Xoridescopus* sp. (ichneumenid).

7. THE RED GRAM BUD WEEVIL *Indozocladius asperulus*

It is a pest of red gram (pigeon-pea) in South India (Fig. 60.28). Apart from red gram it occasionally infests the flower buds of *Gliricidia maculata.*

The adult weevil is minute and brown with a slender snout. It thrusts minute, oval, creamy white eggs into floral buds singly and covers them with a red fluid. The grubs feed on the pollen inside the bud, drop to the ground and pupate in earthen cocoons in the soil. It is only of minor importance on redgram.



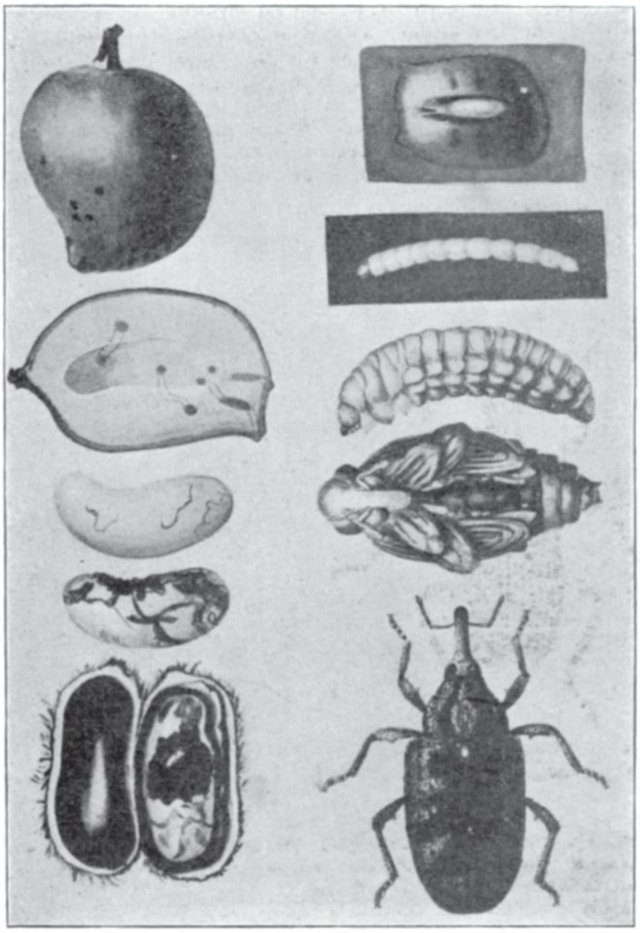
▲ **Fig. 60.28** *Indozocladius asperulus (T.B. Fletcher, 1914)*

8. THE MANGO NUT WEEVIL *Sternochaetus mangiferae*

The insect is popularly known as "nut weevil" or "stone weevil" and is destructive to seeds of mango (Fig. 60.29). The insect is probably of Indian or at least of Oriental origin. It occurs in India, throughout the East Indies including the Philippines and other groups of Pacific Islands, South Africa and Madagascar.

The insect is monophagous and is considered to be the most serious pest of mango. The grubs that hatch out from the eggs laid on developing mango fruits tunnel in a zig-zag manner through the pulp, endocarp and seed coat until they reach the cotyledons. The adults primarily destroy the seeds in fruits and hasten maturity of infested fruits and increase the percentage of fallen fruits. The pulp is damaged, when the adult makes an exit hole in seed and comes out through the pulp, rendering them unfit for consumption. The varieties Neelum, Bangalora, Humayudin, Cherrukkurasam, Baneshan, Peter, Kalepad, Rumani, Bennett, Alphonso, Padiri, Jehangir, Panchadharakalasa, Mulgoa, and Surangudi are attacked by the nut weevil.

The adult weevil is about 6 mm long, dark brown and stout. The female scoops out the surface of developing fruit of one to one and half months old and then deposits the egg one by one. The weevil turns round, scrapes the surface around the egg, and cuts the epicarp rather deep in such a manner that the liquid which oozes out covers the egg and dries up into a resin-like substance. This mark is persistent even on mature fruit and by similar marks the infested fruits can be sorted out to a certain extent. Eggs are laid on fruits till they are half ripe and 12 to 36 eggs are laid on a fruit. The incubation period is about seven days. The grub tunnels into the fleshy portion of the seed and feeds on the cotyledons. As the fruit develops, the tunnels in the fleshy portion gets closed up and will not be visible. The fully grown grub is apodous, fleshy, light in colour with a dark head. It pupates inside the seed itself in a pupal cell and emerges as an adult in seven days. The total life cycle from egg to adult takes about 50 days. A single fruit harbours six to seven weevils in highly susceptible varieties. There is only one brood in a year. Adults hibernate in between the crevices of bark of mango trees or in crevices of stones.



▲ **Fig. 60.29** *Sternochaetus mangiferae. Damaged mango and stages of insect (T. V. R. Ayyar, 1940)*

Control: For an appreciable control of the weevil and fruit fly, spray application of three rounds of fenthion 0.1% or deltamethrin 0.025% at monthly intervals is suggested. The spraying commences 45 days after the fruit is set.

9. THE RICE ROOT WEEVIL *Echinocnemus oryzae*

In India, the insect was first reported in 1924 from Guntur in Andhra Pradesh. It occurs in Tamil Nadu, Kerala and Punjab. The larvae are aquatic and feed on the rootlets of paddy, grasses and *Firnbristylis tenera.* The attacked plants become stunted and do not put forth tillers. It causes a loss of 5 to 10 % in rice crop.

The small brown weevils emerge from cocoons in the soil in paddy fields with the onset of showers of south-west monsoon in Andhra. The damage due to grubs is noticed from July to September for about 2½ months. The small, apodous, translucent, white grubs possess six pairs of prominent tubercles on the dorsal side of the abdomen connected with the tracheal system. They are adapted for aquatic life and absorb air from the air spaces of roots of the host. The grubs cling to and feed on the rootlets. They burrow deep into the soil, pupate and emerge in May or June. There is only one generation in a year. Early rains followed by continuous wet weather is favourable to the pest.

Control: The weevils resting on grasses and paddy after emergence must be killed by spraying with carbaryl 0.1% or chlorpyrifos 0.02%. Application of superphosphate 80 kg/ha acts as a deterrent to grubs and serves to drive them from the active feeding zone of paddy roots.

10. THE GUJARAT RICE ROOT WEEVIL *Hydronomidius molitor*

The insect is known to attack paddy roots in Gujarat causing yellowing of plants even a week after transplanting. Severe attack results in large patches of dead plants.

The adults, which are semi-aquatic, emerge in July and lay the eggs in September around rootlets of rice in the soil. The incubation period is three to four days. The grubs feed on the rootlets of rice and they overwinter at 25 to 30 cm deep in the soil up to May next year. The larval period thus takes about nine months. It pupates in the soil and emerges as adult in 10 to 12 days.

Control: Spray application of chlorpyrifos 0.02% or carbaryl 0.1% controls the adults. Grubs in the soil are controlled by application of phorate 10% granule or lindane 10% granule at 10 kg/ha.

11. THE BRINJAL GREY WEEVIL *Myllocerus subfasciatus*

It is a widely distributed insect, the adults of which are known to cause appreciable damage to brinjal and potato by feeding on the leaves from the edges in a characteristic manner. The grubs feed on the roots of plants and especially in brinjal it causes large scale wilting and drying of mature plants.

The adult weevil lays about 500 eggs in the soil over a period of three months. The grubs that hatch out from the eggs in a week become full grown in two to two and half months and pupate in earthen cells. The adults emerge in 10 to 12 days.

Control: Collection and destruction of the adult and dusting or spraying of chlorpyrifos or carbaryl to kill adults may be done. Incorporating granule of phorate 10 % or carbofuran 3 % at 1 kg active ingredient/ha into the soil before transplanting affords protection to brinjal.

12. THE COTTON ASH WEEVIL *Myllocerus undecimpustulatus maculosus*

Adults of this beetle feed on the edges leaves of and grubs remain in the soil feeding on roots of host plants. When it attacks cotton, the infested plants wilt and dry up. Buds, flowers and tender bolls are also attacked. A single grub is capable of damaging around ten seedlings of cotton. In highly susceptible varieties up to 40 per cent of plants under cultivation succumb to attack.

The adult is small with greyish white elytra having dark lines. It lays ovoid, light yellow eggs in the soil and as many as 361 eggs are laid by a female at a depth of about 8 cm. The incubation period is 3 to 11 days depending upon the climate. The grub is apodous, stout, and fleshy, curved, light yellow and 8 mm long. It pupates in an earthen cell at 3 to 8 cm below ground level. The adults emerge in five to seven days. The total life cycle from egg to adult takes 42 to 54 days.

In India it is known to infest cotton, lady's finger. *Hibiscus cannabinus, Zea mays, Pennisetum typhoideum,* cluster beans, cholam, sugarcane, redgram, ragi (finger millet), mango, *Zizyphus jujuba*, strawberry (*Fraggaria vesca*), pomegranate, apple, *Dalbergia sissoo*, pear, peach and plum.

Control: Addition of carbofuran 3 per cent granule into the soil before sowing at 1 kg a.i./ha and drenching the soil with chlorpyrifos 0.02% emulsion in a standing crop when infestation is noticed are suggested.

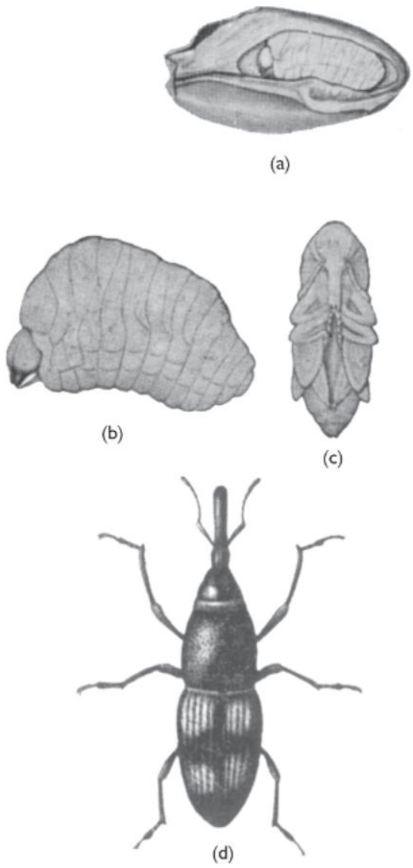
13. THE RICE WEEVIL *Sitophilus oryzae*

A cosmopolitan insect which is known to be a serious pest of stored rice especially in the tropics (Fig. 60.30).

The adult weevil is reddish brown about 4 mm long and has four light reddish or yellowish spots on elytra. It infests the grain both in the field and in storage. Apart from rice it is also highly destructive to stored grains like wheat, corn, sorghum, etc. Both adults and larvae feed on them and the grains are damaged beyond use.

The adult female bores a hole in the grain kernel, deposits a single egg and covers it with a gelatinous fluid. A female may lay as many as 300 to 550 eggs in four to five months. The incubation period is three days. The grub is apodous, short, stout and whitish with a brown head and becomes fully grown in three to four weeks. It pupates inside the grain and emerges as an adult in three to six days. The adult longevity is four to five months. In a year there may be about five to seven generations.

Control: Mixing wheat seeds with malathion dust at 24 ppm affords protection against the beetle attack for about four months.



▲ **Fig. 60.30** *Sitophilus oryzae: Top (a) Larva in wheat grain, Middle (b, c) larva and pupa, Bottom (d) Adult (H. S. Pruthi, 1969)*

14. THE MANGO LEAF CUTTING WEEVIL *Deporaus marginatus*

It is a serious pest of mango grafts in the nurseries. The female weevil cuts the tender foliage after oviposition and defoliates the grafts. New vegetative growth is also damaged. Mating takes place throughout the day. The female before oviposition selects a leaf, moves to the dorsal surface, makes a minute cut by the side of the midrib and prepares a C-shaped pouch for an egg. Then it turns about and bends the abdomen slightly to lay an egg inside it. Soon after oviposition it turns around again and repairs the opening of the pouch. The average size of pouch is 1.1 mm long and 0.5 mm broad. The distance between two pouches is about 1.89 cm. Three-quarters of the outer edge of the leaf is utilised for egg laying leaving the remaining still attached to the plant. The mean pre-oviposition and oviposition period is respectively 1 and 53 days. A female cuts on an average 66 leaves during its life and lays around 134 eggs. The egg is white, cylindrical with both ends rounded and measures 0.7 mm long and 0.3 mm broad. Mean incubation period is 2.5 days. The grub on hatching mines and feeds between leaf surface exhibiting small narrow galleries full of excreta. The grub passes through three instars in seven to nine days. The fully grown grub bores its way out of the withered leaf, enters into the soil and pupates in an earthen cell.

15. APPLE WEEVIL *Dyserus clathratus* (Pasc.)

This species is a pest of apple in Meghalaya and Arunachal Pradesh. The other two species reported from India, infesting apple are, *D. malignus* and *D. fletcheri.* Adult weevil is small, black or brownish and measures 1.0 to 1.25 mm long with a prominent snout. The weevil scars the surface of fruits by feeding and laying the eggs therein. The grubs feed inside the fruits until pupation. The fully grown grub is white, 0.8 to 1.0 cm long. Around two to three grubs are noticed in a fruit. The attacked fruits fall down prematurely or become malformed.

16. THE PALM POLLINATING WEEVIL *Elaeidobius kamerunicus*

This species is very important in the pollination of palms. Commercial cultivation of oil palms in the Andamans started in 1976 but inadequate pollination was one of the major reasons for the bunch failure in oil palm. Therefore, this species was introduced in Little Andamans from the Central Plantation Crops Research Institute, Research Centre, Palode, Kerala in September 1986. The introduction of the weevil resulted in perfect fruit setting and increase in the bunch weights.

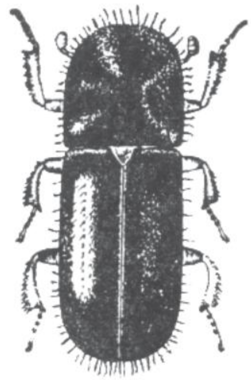
Family Scolytidae (Bark or Engraver Beetles, Ambrosia or Timber Beetles)

The scolytids are small, cylindrical, brownish or blackish beetles, rarely over 6 or 8 mm in length. They feed on the inner bark or wood of trees.

The adults and grubs of bark beetles mine under bark. Some attack recently cut logs or dead logs or branches and others tunnel extensively in living trees causing ultimate death of such infested trees. The adults excavate characteristic brood galleries in which they oviposit. The grubs excavate tunnels in characteristic patterns under the bark which vary in different species. They pupate in the tunnels. The adults eat through the bark making small round holes and escape.

The timber beetles feed on fungi grown in their galleries caused by tunnelling into the hard wood of trees. In timber the damage is done chiefly by tunnelling. The adult females in most cases feed and take care of the grubs till they become fully grown and pupate. Each species of beetle grows its own preferred type of fungus. The adults, when they emerge carry with them the conidia of the fungus which are introduced and grown in the galleries that are made in the new host.

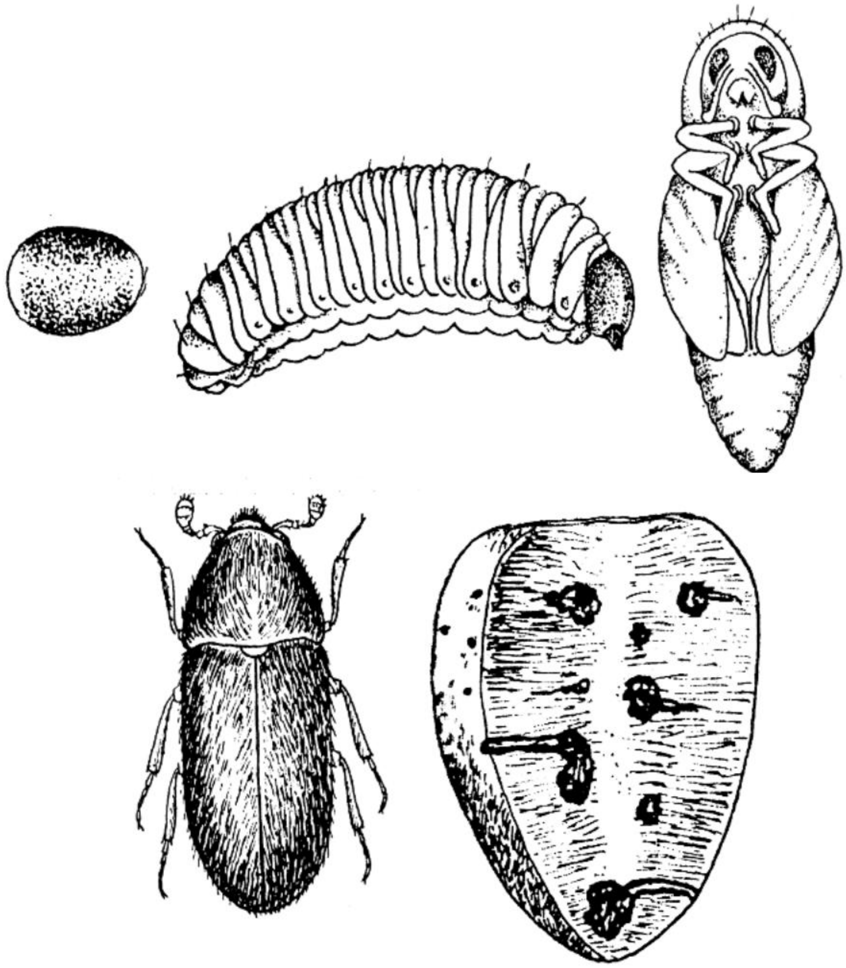
The common species that are economically important in India are : *Xyleborus morstatti* on avocado and coffee, *X. parvulus* on coconut, *X. semigranosus* on tea, *X. biporus* on rubber, *X. compactus* on coffee and *Coccotrypes carpophagus* on stored areca nut and seeds of *Anona squamosa*. *Euwallacea fornicatus* (Fig. 60.30) infests castor, tea and coffee. The coffee berry borer *Hypothenemus hampei* is of considerable importance in the recent years.



▲ **Fig. 60.31** *Euwallacea fornicatus (T.B. Fletcher, 1914)*

1. THE DRY NUT BORER BEETLE *Coccotrypes carpophagus* (Fig. 60.32)

This species has a world wide distribution and formerly known under the names *C. anonae, C. brevis, C. integer, C. nanus, C. pygaeus* and *C. rolliniae*. The beetle damages stored seeds of *Anona squamosa* and *Areca catechu* (arecanut) in India. The damage is caused by the reddish brown cylindrical beetles boring into the dry nuts and tunneling within them. The internal contents are pulverised into fine powder and holes of 0.6–1.00 mm diameter can be seen on the surface of nuts. The female beetle tunnels towards the central core of the nut and a small irregular chamber is constructed. The beetle lays 38–43 creamy white oval eggs. The grub is milky-white with a light brown head, apodous with scanty minute hairs on body and measures 2.50-2.75 mm long. The larval period lasts for 12–16 days. Pupation takes place inside the chamber and the adult emerges in four to five days. The total life cycle occupies 22–29 days.



▲ **Fig. 60.32** *Life stages of Coccotrypes carpophagus Horn. (1) The egg chamber inside the nut. (2) Egg, (3) Fully grown grub, (4) Pupa, (5) Adult, (C.N. Oommen and M.R.G.K. Nair, Entomon)*

2. THE COFFEE BERRY BORER *Hypothenemus hampei* (Ferrari) (Fig. 60.33)

It is a native of Africa and considered to be one of the most serious pests of coffee in many of the world's coffee producing countries. It was reported in 1990 as a major pest on coffee in the coffee estates of Gudalur, Nilgiris district. The black, adult female beetle measuring 1.8 mm long bores into young as well as ripe berries, the point of entry usually being the naval region. Inside the berries, they make tunnels wherein the eggs are laid. The larvae, on hatching, cause further damage by feeding on the tissues. In case of severe infestation the berries drop prematurely. However, yield loss due to damage by feeding and reduction in quality are the major economic problems. In extreme cases up to 90% damage to berries in the coffee plantations occur, resulting in 80% loss in yield. Population of beetle increases during August, reaches the peak in September/October and starts declining from December onwards.

Control. Spray application of endosulfan 0.02% or quinalphos 0.0125% is suggested.

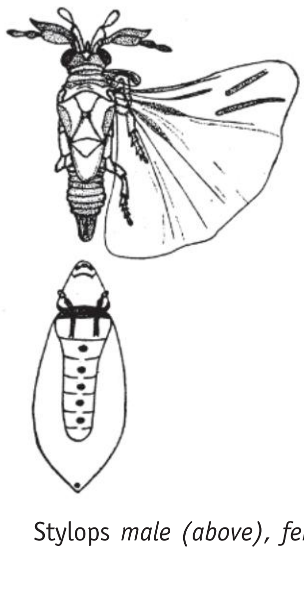
▲ **Fig. 60.33** *Hypothenemus hampei: 1.Adult (greatly magnified) 2. Borer and feeding gallery 3, 4. Injury caused by larvae 5. Berries showing characteristic injuries. Note arrangement of holes bored within the mark left by the calyx of the flower. In several of the galleries, the white mycelium plug of a fungus may be detected. This fungus occasionally attacks the pest in the berry when there is very high relative humidity. 6. Beans damaged by S. hampei. (Bayer, A.G., 1968)*

◆ Chapter 61

Order Strepsiptera

Stylopids or Twisted-wing parasitoids

Strepsiptera comprises remarkably small insects whose larvae are known to be internal parasites of members of the family Lepismatidae of Thysanura, Blattidae of Blattodea, Mantidae of Mantodea, Gryllidae, Gryllotalpidae, Tettigoniidae and Tridactylidae of Orthoptera, Delphacidae, Membracidae, Cicadellidae, Cercopidae, Dictyopharidae, Eurybrachidae, Ricaniidae, Flatidae, Fulgoridae, Issidae and Tettigometridae of Homoptera, Coreidae, Cydnidae, Lygaeidae, Pentatomidae and Scutelleridae of Heteroptera, Tephritidae and Platysomatidae of Diptera, Formicidae, Masaridae, Eumenidae, Vespidae, Sphecidae, Colletidae, Halticidae and Andrenidae of Hymenoptera. Economically they are of little or no importance to man as their role in biological control of pest species is very much limited.



▲ **Fig. 61.1** Stylops *male (above), female (below)*

The order Strepsiptera was formed by Kirby in 1813. It is a monophyletic group. The primitive characters as well as the specialisation of Strepsiptera go against their origin from Coleoptera. However, it has been opined that the use of hindwings for flight, and the modification of metathorax to accommodate the flight muscles in Strepsiptera and Coleoptera may have a sister-group relationship. The stylopids are minute insects and exhibit a marked sexual dimorphism (Fig. 61.1). The male is winged, whereas the female is larviform, apterous and apodous and in most cases lives throughout its life as an endoparasite in a puparium which projects like a lump from the body of the host.

About 450 species of stylopids are known from the world, the majority being from the Holarctic region. Information on the Indian species of this extremely interesting group is restricted to the contributions of Pierce (1909,[1] and Subramanyam (1922,[2] and 1932). *Pyriloxenous compactus* is parasitic on delphacids and jassids in India, especially on the mango jassids, *Amritodus atkinsoni* and *Idioscopus clypealis.* The other known species are *Tachytixenos indicus* on the wasp *Tachytes* sp., *Indoxenos membraciphaga* on the membracid *Otinotus pallescens,* and *Tridactylophagus mysorensis* on the black cricket *Tridactylus* sp.

Adults and Their Characteristic Features

Adult Male: It is short-lived, dark brown or black, and measures 1.5 – 6.0 mm. The antennae are conspicuous and flabellate and are seven segmented in primitive forms or reduced to six, five or four segments. They possess sensilla trichodea and sensilla basiconica; the fourth segment having a sensory depression- Hofeneder's organ, which in the Elenchidae and Bohartillidae is on the third segment. The sense organs of the antennae determine the presence of the female odour. Each compound eye has 15 – 150 ommatidia separated by strips of cuticle or setae; the number of ommatidia being constant within a species.

The mouthparts consist of mandibles and maxillae whereas mandibles are absent in Corioxenidae. The mandibles are blade-like, conical or knife-shaped and may be sclerotised or weakly sclerotised with hairs. The basal segment of maxilla is fused to the head (Halictophagidae) and has an unsegmented proximal segment. The mandibles and maxillae have become sensory organs as they have lost their function as the buccal apparatus. The labium, hypopharynx and part of the labrum form a membranous area between the mandibles and maxillae ventrally. In primitive forms the clypeus and frons are separated. The labrum is fused with the clypeus whereas in *Stylops* it is free.

The head is connected to a short and small prothorax by an extensive neck. The anterior pair of wings attached to the mesothorax are reduced in size and look like 'halteres' in all males whereas the females are wingless. The metathorax possesses the hind wings and is

[1] Pierce, W.D. 1909. *Bull. U.S. Nat. Mus.,* **66**, xii + 232 pp.
[2] Subramanyam, T.V. 1922. *Bull. Entomol. Res.* **12**: 465–467.
Subramanyam, T.V. 1932. *Records of the Indian Museum,* **34**: 43–46.

much larger than the mesothorax as the indirect flight muscles are enlarged in the former; and strikingly the postnotum is long and saddle-shaped. The hind wings are large with longitudinal veins and reduction in radial venation.

The fore- and middle legs are with free-standing coxae devoid of sternal articulation and trochanter. In most Strepsiptera the metathorax is fused with the pleurosternum and the hind pair of legs begin with the trochanter. The tarsi are five-segmented with terminal claws (Mengenillidae, Mengeidae and Triozocerinae), one to four segmented without claws (most other families), or four-segmented with a weak claw-like structure (Corioxenidae and Uniclavinae).

Abdomen is 10-segmented, the first-segment being closely fused to the metathorax. The ring-shaped ninth segment bears the copulatory organs, and on its caudal surface has a groove into which the aedeagus can be withdrawn. The tenth segment forms a dorsal cover for the aedeagus. The aedeagus and phallobase articulate with the ninth segment and the former has a tapering acumen and a shaft or scapus; the parameres are absent.

Adult female: The neotenic female varies enormously in size ranging from 2.0 to 8.0 mm depending on the size of the host. When fully mature the whole abdominal cavity of the host is filled with the female, sometimes occupying even the thoracic cavity, thus displacing the organ systems of the host against the body wall. The sexually mature female is 'larviform' (except Mengenillidae) and lacks distinct antennae, mouthparts, eyes, wings, legs and external genitalia. It is distinct with fused head and thorax having a brood canal opening through which the female is inseminated by the male. The abdomen is eight segmented, soft and separated from the thorax by a constriction. Opening into the brood canal on abdominal segments two to five are one to five unpaired genital tubes. The brood canal in turn opens to the exterior through the brood-canal opening. It is believed that Nassonov's glands present on the cephalothorax are the source of pheromone that attracts the males. In the Mengenillidae the female is free-living, apterous, and has a distinct head with antennae, a thorax with legs and a genital opening (with no gonopophyses).

Internal Anatomy

The alimentary canal is simple and unconvoluted. In the male it consists of the fore-, mid- and hindgut, the latter two parts of the intestine having no communication between them. The hind intestine is atrophied in the female and an anal opening is wanting. Malpighian tubes are absent.

The brain is larger in the male than in the female. A common ganglionic mass is formed by the fusion of all the ventral ganglia up to and including the ganglia of the second and third abdominal segments. To this mass are attached the paraoesophageal connectives. The median abdominal nerve cord terminates in the posterior ganglia.

In the male, the reproductive organs are paired structures which open to the exterior by means of a common duct. In the female, the reproductive organs degenerate and the egg masses are scattered through the body space, and funnel-like tubes formed of cuticular invaginations function as genital ducts. The genital pores may vary from two to five dispersed segmentally on the median ventral region of the second and following abdominal segments.

Biology

Fertilisation takes place by haemocoelic insemination. The Strepsiptera comprising the endoparasitic neotenic females (Stylopidia) and the free-living females (Mengenillidia) produce viviparously small larvae measuring 0.08 to 0.30 mm long in large numbers which may vary from 1000 to 750,000, and they live only for a short time. The Strepsiptera exhibit hypermetamorphosis, and two or more morphologically distinct successive larval instars suiting the different modes of parasitic life are evident. The eggs lie dispersed in the haemocoele. Polyembryony has been reported in *Halictoxenos simplicis.*

Adults are sometimes attracted to light or caught in sweeps or traps. It has been reported that in *Coriophagus rieki* Kinzelbach, the male is active from 8 a.m. to 5 p.m, and when a female is found, it grasps it at the narrow base of the cephalothorax by its greatly expanded forelegs, while the tibiae grasp the sides. The aedeagus is then inserted into the brood passage opening rupturing the surface. Though the host is agitated before copulation it remains quiescent during copulation. The male dies within 10 minutes after copulation. Sometimes the aedeagus is seen inserted in the female's cephalothorax and it is presumed that it may be due to the male being knocked off the host because of movements like brushing of the hind legs.

The life history has been investigated fairly well with reference to *Xenos vesparum* in Russia. The males live only for a few hours after emergence from the host and are free-living. The females remain permanently inside the body of their host, the wasp or bee, and only the cephalothorax is visible outside through the body wall of their host. The male alights on the host, inserts its aedeagus into the aperture of the brood canal of the female. There is also the possibility of parthenogenetic development in some cases. The larvae which hatch out from the eggs in large numbers within the body of the female get into the brood canal through the genital pores and they emerge out finally through the aperture of the brood canal. The young larvae, otherwise known as 'triangulins', are very small and characterised by serrated thoracic and abdominal sclerites, smooth tergites, spine-like tarsi and pairs of long caudal setae, which enable them to cling to the host or vegetation while awaiting a suitable host. It is presumed that the larvae, which remain upon the body of the host, are probably liberated on to flowers and in other situations, from where they attach themselves to other host individuals. They are carried by the host insects to the nests wherein, the larvae speedily burrow into the body through the body wall and become internal parasites. Inside the host the second instar larva assumes a maggot-like apodous form. In the third and subsequent instars the sexes can be distinguished wherein the male possesses a bulbous head and three pairs of rudimentary legs. The absorption of nutrients from the blood of the host takes place through the thin cuticle of the parasitoid. The parasitoid protrudes from the abdomen of the host at its final moult which coincides with the pupal stage of the wasp or bee. The male parasitoid pupates in the exuviae of the preceding instars and the adult emerges by pushing open the operculum. It has been reported that the excretion of meconium, together with the contraction of the abdomen during the rhythmic pulsations, facilitates the emergence of the male through the opening of the puparium. In the female, the flattened disc-like cephalothorax will be found protruding outside the body of the host, the other portions remain within the abdomen of the host. In Stylopidae it is believed that the tooth-edged mandible is used to cut open the cephalotheca or the cap of the puparium and the ptilinum in Corioxenidae. The insects that have been attacked by stylopids are said to be 'stylopized'.

Host-parasitoid Relationship

Host-parasitoid relationship in terms of morphology, behaviour and dispersal has been studied by various workers with reference to effects on the host. It has been shown that in *Andrena* (Hymenoptera) stylopized males tend to resemble normal females and stylopized females resemble normal males. Further, in stylopized males there is some approach to foveae-like formation (oval shallow area on each side of the face). The other effects noticed include: third segment of stylopized males may be elongated and slender which in stylopized females may be shortened and thickened. Stylopized female has reduced pollen-collecting apparatus whereas the stylopized male exhibits a marked development of the basitarsus; the anal fimbriae of normal female is shortened or occasionally absent in stylopized female whereas it may be present sometimes in stylopized males. The above are some positive acquisitions of secondary sexual characters. It has been shown that in contrast to Hymenoptera in the Homoptera there is no positive acquisition of either sex or morphogenetic characters from the opposite sex.

As far as effects on behavioural aspect is concerned, lack of vitality, pollen-collecting instinct and loss of power of flight in stylopized Hymenoptera have been observed.

The dispersal in Strepsiptera achieved by the free-living first instar larvae is referred to as active dispersal. It has been reported that in most Strepsiptera parasitising Homoptera, the first instar larvae reach their hosts by 'direct' parasitisation. The second and third instars of the host are found in the same habitat as the adults and thus the first instar larvae emerging from the neotenic female may remain on the vegetation awaiting a new host and parasitise. Interestingly in the case of the rice brown plant hopper (BPH), *Nilaparvata lugens* the first instar of *Elenchus* larvae parasitic on BPH merge from neotenic females at a place far away from their future nymphal hosts. The carrying over of the parasitoid is achieved by the migratory, macropterous females which disperse the first instar larvae to rice crop infested by BPH nymphs and this phenomenon is attributed to phoresy. On the other hand, in the case of Strepsiptera parasitising Hymenoptera a "carrier' is needed as the first instar larvae are required to reach the host larvae hidden in the nests. It is mainly because the stylopized females do not build nests at the same time as the emergence of the first instar larvae. Therefore, the possibility of direct transfer to the host larvae in the same nest is remote. The dispersal of the first instar larvae from flowers to the nest of the host was thus made possible by a bee or wasp. Similarly, the foraging worker ants would carry the first instar larvae of Strepsiptera back to the nest, which would then parasitise the ant larvae.

The dispersal achieved by the stylopized hosts is referred as passive dispersal and has been observed in macropterous Delphacidae. In the case of *N. lugens,* it was presumed that by the time the parasitoid became a neotenic female, the host would be already present as colonies in the freshly planted rice. It is also assumed that no further flight took place.

Classification

Two suborders viz., Mengenillidia and Stylopidia were recognized by Kinzelbach in 1969.

Suborder MENGENILLIDIA

It is represented by two families viz., Mengeidae and Mengenillidae.

Family Mengeidae

A fossil family from the Baltic amber represented by the male of a single species *Mengea tertiaria* (Menge).

Family Mengenillidae

Characterised by free-living adult female with a single genital opening and forewing of male with MA_1. They are parasitic on Lepismatidae and are readily distinguished from others by the male possessing five-segmented tarsi with claws. Distributed in Circum-

Mediterranean region, South East Asia, East Asia and Australia. Three subfamilies viz., Mengenillinae, Iberoxeninae and Congoxeninae are recognised.

Suborder STYLOPIDIA

These are endoparasitic, females with a number of genital openings and forewing of male with MA_1. The following seven families have been recognised.

Family Corioxenidae

These are parasitic on members of Hemiptera (Heteroptera). Distinguishing characters are: separation of thorax distinctly and female lying with ventral side turned towards host, seventh segment in female with genital aperture; rudimentary ommatidia on cephalothorax; in male antenna five to seven segmented, with lateral flabellum on third and fourth segments; tarsi four to five segmented — if five segemented with claws and if four segmented with claw-like structure or with no claws. Three subfamilies have been recognised: Corioxeninae, Triozocerinae and Uniclavinae.

Family Halictophagidae

These are parasitic on members of Blattodea, Orthoptera, Hemiptera and Diptera. Distinguishing features are: Tarsal segments three with no claws; antenna six to seven segmented, with lateral flabellum on third, third to fourth or third to sixth segments; cephalothorax of female flattened; first to fifth abdominal segments with one genital aperture each; the brood canal opening is narrow, linear or oblong. Four subfamilies have been recognised: Dipterophaginae, Tridactylophaginae, Coriophaginae and Halictophaginae.

Family Callipharixenidae

These are parasites of Heteroptera. Distinguishing features of female are presence of functional metathoracic spiracles and elongated cephalothorax. These are known from Cambodia and Thailand.

Family Bohartillidae

Known only by males and have the following distinguishing features: Antenna are seven-segmented with lateral flabellum only on third, fifth and sixth segments; mandibles are short and flat; maxillary base is large; and wings with MA_1.

Family Myrmecolacidae

These parasitise members of Mantodea, Orthoptera and Hymenoptera. Distinguishing features are: The cephalothorax of adult females with hook-like projections behind spiracles; more than five genital apertures on each of the second and third abdominal segments brood canal opening crescent shaped. In adult male, antenae are seven-segmented with narrow, round joints; spoon-shaped subalare absent on metathorax.

Family Elenchidae

The members are parasites of Delphacidae, Eurybrachidae, Fulgoridae, Ricaniidae, Flatidae and Dictyopharidae. Distinguishing characters are: Tarsi two-segmented without claws; antennae four segmented with lateral flabellum on third segment. Adult females are without hook-like projections on cephalothorax; one to five genital apertures on each of the second and third abdominal segments; brood-canal opening not crescent shaped.

Family Stylopidae

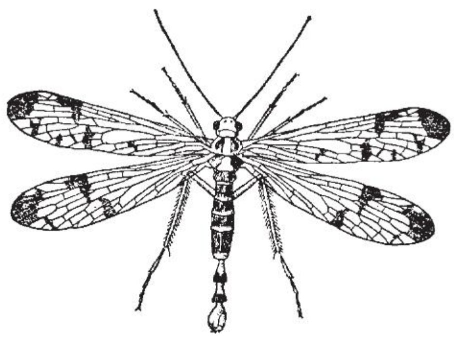
These are parasitic on Hymenoptera (Apoidea, Sphecoidea and Vespoidea) and are of cosmopolitan distribution. In adult males the antennae are four to six segmented with broad, flat joints; and spoon-shaped subalare on metathorax. In adult females the cephalothorax is flattened dorsally, sclerotised and lying close to host abdominal segment; brood-canal opening is slit-shaped; and three to six abdominal segments, each with one genital aperture. Subfamilies recognised are: Xeninae, Stylopinae and Paraxeninae.

◆ Chapter 62

Order Mecoptera

Mecoptera includes the scorpion flies (Fig. 62.1), so called because the males in many species have the terminal segments of the abdomen raised in the manner of scorpions. They are carnivorous, essentially terrestrial insects, with an elongate beak-like head, frequenting shady places and are often met with in herbage or rarely under stones. In distribution they are mostly subtropical and temperate but some genera like *Panorpa* and *Bittacus* are cosmopolitan.

The hypognathous head has the anterior region prolonged into a rostrum, formed by the head capsule, clypeus, labrum, gena and the proximal portions of the maxillae and labium. Well developed compound eyes, three ocelli and a pair of filiform antennae with 16 to 20 segments in *Bittacus* or 40 to 50 in *Panorpa* are borne on the head. The mouthparts are mandibulate, the mandibles elongate, and apically toothed; the maxillae are well developed with all parts well differentiated, the lacinia and galea large and hairy and the palp five-segmented; the labium has an elongate sub-mentum, the ligula absent and palpi one- to three-segmented.



▲ **Fig. 62.1** *An adult scorpionfly (from B.D. Moreton)*

Very rarely as in *Nannochorista* there is a distinct tendency for the mouthparts to become suctorial, the mandibles being vestigial, and the labrum forming a sharp projection.

The prothorax is small and the meso- and metathorax are better developed. Legs are long, with elongate coxae placed close together and generally adapted for walking; tarsi five-segmented and with paired claws. In *Bittacus* and its allies (Bittacidae) the tarsi are raptorial, the fourth and fifth tarsal segments are strongly dentate on their inner margin, the fifth closing on to the fourth and there is only a single claw. The wings are membranous, almost subequal and held horizontally in repose. In some families like Boreidae they may be absent or vestigial. The venation is primitive, almost all the main veins, their branches and cross veins are present. The R_3 is usually dichotomously branched and the anal region is invariably small and reduced. There are ten distinct segments in the abdomen and in the females the terminal segments, in particular segments from seven to ten, are narrowed, cylindrical and telescoped. The hind margin of the ninth sternite in the males is prolonged and deeply cleft into two styliform arms, while the tergum of the ninth segment is a sub-quadrate plate. A pair of two-segmented claspers is present in between the tergal sternal processes of the ninth segment. These appear to represent the phallic parameres, the basal segments usually termed the basimere and the distal, with the ninth segment, the telomere. They may be stout and closely associated as in *Panorpa* or more slender and well apart as in *Meropi*. The aedeagus is highly variable in different species and may be oval or flattened structures with a pair of dorsal arms. The inconspicuous tenth segment carries a pair of two-segmented cerci. The alimentary canal is an almost straight tube, enlarged in the region of the proventriculus and midgut and with a convoluted hindgut. The oesophagus has two dilatations serving as a sort of pumping apparatus. The salivary glands are tubular and the malpighian tubes are six in number. The respiratory system has two pairs of thoracic and eight pairs of abdominal spiracles, while in the nervous system there are three thoracic and about five to eight abdominal ganglia, the ganglion of the basal segment being invariably shifted forwards to the metathorax. In the female reproductive system, there are variable numbers of polytrophic ovarioles, sometimes reaching as many as 25. In the males the testes are made up of three to four follicles and the vasa deferentia is highly convoluted in most species. The larvae are typically cruciform almost looking like a caterpillar, with a large head, strongly toothed mandibles, 20 to 28 simple eyes, three-segmented antennae, and four to eight prolegs in addition to true thoracic legs. On the tergum of the tenth segment is a peculiar lobed retractile vesicle. Pupation takes place generally underground.

Suborder PROTOMECOPTERA

Wings are short and broad, males without swollen genitalia; body generally depressed.

Suborder EUMECOPTERA

Wings are narrow and slender. Male genitalia is swollen, body generally cylindrical.

Family Panorpidae

Wings are well developed and tarsi two-segmented. Females without conspicuous ovipositor; legs are not very long, normal, e.g. *Panorpa*.

Family Boreidae

Wings are rudimentary; legs normal and tarsi two-segmented; labial palpi short; ovipositor conspicuous in females, e.g. *Boreas*.

Family Bittacidae

Legs are very long and slender, with only one claw, raptorial tarsi. Abdomen of males not scorpion-like, e.g. *Bittacus*.

◆ Chapter 63

Order Siphonaptera

The Siphonaptera or fleas include small, laterally compressed, wingless, bloodsucking insects, mostly ectoparasitic on warm-blooded animals, living among the hairs of mammals, feathers of birds and in the nests of their hosts. Their importance is due to their role as vectors of plague in man and as intermediate hosts of many parasitic helminths.

The bodies of fleas are strongly compressed and sclerotised, with a prominent armature of backwardly directed spines and bristles, enabling them to progress more easily through the hairs or feathers of their hosts. The generally triangular head is closely articulated to the thorax and in some species like *Ctenocephalides canis* and *C. felis* the ventral margin of the head bears a general comb, formed by a number of stout, backwardly inclined, black spines. The antennal groove placed behind the eyes divides the head into two regions - an anterior frons and a posterior occiput. The short, stout three-segmented antennae lie within this groove. The terminal segment of the antennae is club-like and is variously subdivided to look like miniature segments. Compound eyes and ocelli are mostly reduced or wanting and when present, the eyes lie in front of the antennae, represented as dark, pigmented lateral spots. In some fleas, inter-antennal grooves connect the two antennal grooves, imposing a restriction on the freedom of movement of the head.

The mouthparts are adapted for piercing and sucking. Mandibles are absent and the laciniae of the maxillae (earlier thought to represent the mandibles), which are broad, long and blade-like are important feeding structures. Each lacinia is serrate along its outer margin of its distal two-thirds, and is also grooved. They are closely apposed basally. There is a ventrally grooved epipharynx, which is closely approximated with the lacinia, forming the food channel. The labrum is small and reduced and situated at the base of the epipharynx. The hypopharynx is represented by a small sclerite and the salivary duct opens into it. The maxillary palp is four-segmented. The labium is made up of two portions, a postmentum partially fused with the head and a prementum carrying the normally five-segmented palp. The two palpi form a sheath or tube within which lie the laciniae and the epipharynx.

The thorax is made up of three-segments and as in the case of the head, the posterior margin of the pronotum bears a strong row of black, stout spines in some species often forming the pronotal comb. The coxae of the legs are large, the legs elongated and well developed for leaping and quick movements, the last pair being often larger than the others. The femora are stout, the tarsi bearing five segments and ending in two strong claws.

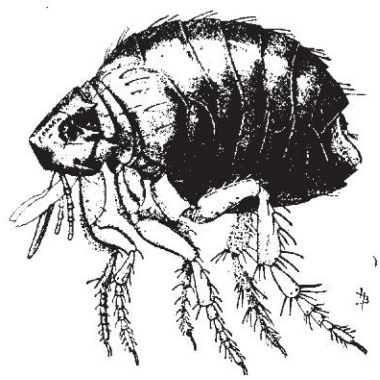
Of the ten abdominal segments, the last three are modified in connection with the reproductive structures. The sternum of the first segment is absent, while in the males the tergum of the ninth segment is reduced. The aedeagus in the males is a complex structure, and a pair of two-segmented claspers are present on either side, articulated to a projection of the ninth sternum.

The alimentary canal has a well sclerotised pharynx, short oesophagus, a conical proventriculus, a stomach, which is frequently dilated, a large midgut and a hindgut with four to six rectal papillae. Four malpighian tubules are present. The salivary glands are paired ovoid sacs, the salivary ducts opening beneath the hypopharynx. The proventriculus is bulbous and internally bears seven rows of epithelial spines, which will occlude the opening when the rows close by contraction of the muscles of the stomach. This actually aids in contaminating blood of the host animal. The respiratory system is well developed and ten pairs of spiracles—two thoracic and eight abdominal—are distinct. In the nervous system the ventral nerve cord bears three thoracic and seven to eight abdominal ganglia and the intervening connections are very short. The testes in the males may be follicular, globose or mostly fusiform, leading into vasa deferentia, generally coiled basally and distally uniting to form a ductus ejaculatorius. Two pairs of accessory glands open into the vasa deferentia. The ovaries have four to eight panoistic ovarioles. The vagina opens on the sternum of the eighth segment and a conspicuous spermatheca is present which has taxonomic value in studies on systematics of fleas.

In general, the life cycles of fleas are of interest. The ovoid eggs, mostly whitish or creamy, are deposited in nests or burrows of the hosts. They are never glued to hairs or feathers. The young larvae are minute, elongate, active, legless and without eyes. They move about in the debris near the nest, feeding on organic matter. When food is in plenty, development is rapid. The mature larvae are slender, each segment of the body being provided with a number of bristles, helping in crawling and with a distinct head and mouthparts of the biting type. To aid in the locomotion the apex of the abdomen bears a pair of fleshy processes. The larvae spin silken cocoons when they become fully mature and dust particles adhere to these cocoons. The mature larva moults into the pupa within the cocoon. The pupal stage varies in its duration from five to seven days to 354 to 450 days in some European species. Fleas breed in cracks and crevices of buildings, in dust and debris, in sheds, chicken houses, garbage dumps, etc.

Several families are recognised and more than 1200 species are known. The family Pulicidae is most widely distributed, including the human flea *Pulex irritans*; the Indian rat flea, *Xenopsylla cheopis*, the primary vector for human bubonic plague; *Ctenocephalides canis* and *C. felis*.

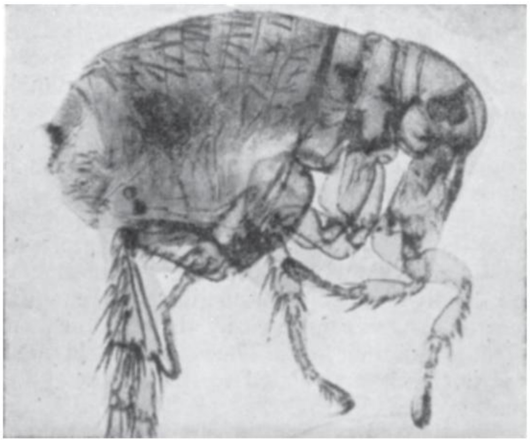
Among other families, *Echidnophaga gallinacea* (Fig. 63.1) is an important pest of poultry.



▲ **Fig. 63.1** *Echidnophaga gallinacea,* adult female (*courtesy: USDA, Washington*)

Fleas and Man

Fleas are a source of considerable annoyance because of the irritation and itching produced as a result of their bites. But their role as intermediate hosts of some tapeworms commonly parasitic on man and as transmitters of bubonic plague is of considerable importance. The larvae of the dog flea *Ctenocephalides canis* and the human flea *Pulex irritans* (Figs. 63.2 & 63.3) consume the eggs of *Dipylidium caninum*, the common tapeworm of



▲ **Fig. 63.2** *Pulex irritans, female (courtesy: Joseph)*

▲ **Fig. 63.3** *Pulex irritans male* (*ibid*)

dogs and cats. Hatching of the tapeworm embryos takes place within the larval fleas and they penetrate the wall of the gut and remain within the body cavity till the fleas become adults. Infections are caused by ingestion of fleas by the dogs and cats. Close association with such pets results in children getting infected.

Xenopsylla cheopis, the common Indian rat flea, is the primary vector of bubonic plague caused by *Bacillus (Pasteurella) pestis* and is spread through the flea-bites. The fleas are not really intermediate hosts, but mainly act as reservoirs and culture media of the bacillus. Plague is mainly a disease of rodents and rats die in large numbers and only then it spreads to man. Apart from *X. cheopis*, other flea vectors also known are - *X. astia* in the drier parts of this country and *Pulex irritans, Ctenocephalides canis* (Figs. 63.4 and 63.5) and *C. felis* during epidemics.

▲ **Fig. 63.4** *Ctenocephalides sp., adult female* (*ibid*)

▲ **Fig. 63.5** *Ctenocephalides sp., adult female, anterior end enlarged* (*ibid*)

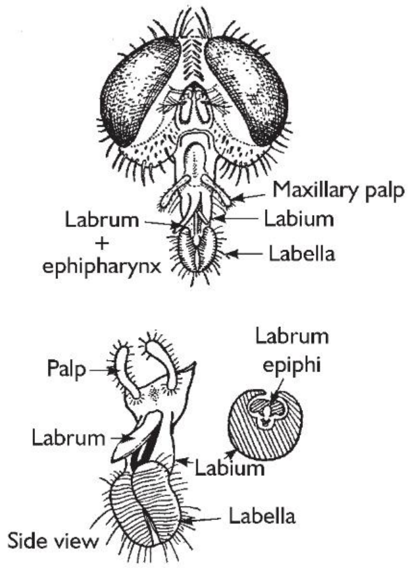
Destruction of fleas on dogs and cats is achieved by treatment with fenitrothion 0.05% or deltamethrin 0.025% emulsion. Spraying the above all over and around the house helps in the control of fleas infesting houses. Absolute cleanliness is a prerequisite for preventing flea infestation. Rat proofing of buildings, and careful usage of rat poisons also help in the prevention of spread of plague.

◆ Chapter 64

Order Diptera

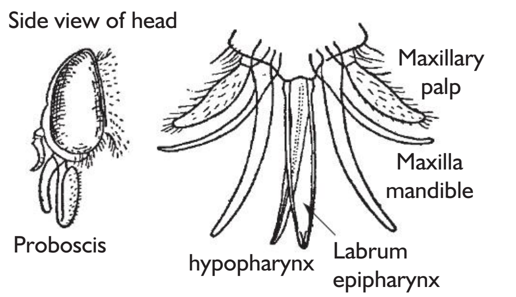
The diptera comprising a large group of insects including the common flies, mosquitoes, gnats and midges, are characterised by the possession of only the mesothoracic pair of wings. The hindwings are reduced to a pair of short, knobbed structures called the halteres. The adults and larvae have a variety of habits and their mouthparts are adapted for piercing and sucking or rasping and lapping and in some as in the robber flies, the botflies, etc., they are vestigial. Some of them are predaceous, others bloodsucking and yet others feed on nectar or plant sap and decaying animal and vegetable matter. The legless larvae (maggots) are usually moisture loving and may be parasitic on insects as in tachinids or on human beings and animals as in flies producing myiasis, or gall-producing like cecidomyiids or predaceous as in the larvae of syrphids or hoverflies or scavenging as in flesh flies or sarcophagids. The vectors for malaria, filaria, dengue, kala-azar and black fever, sleeping sickness, encephalitis, etc. are of great impotance to man.

The head of the adult Diptera (Fig. 64.1) is large and freely movable and most of it is occupied by the compound eyes, which are larger in males. The eyes may be continuous (holoptic) or distinctly separate (dichoptic). Three ocelli, arranged in a triangle, are usually present between and a little behind the compound eyes. In some specialised Diptera there is a distinct, inverted 'U' like frontal suture, just above the antennae. A bladder-like cephalic structure, the ptilinum or frontal sac is a characteristic feature of Cyclorrhapha and helps in the splitting off of the anterior end of the puparium. The ptilinum is forced out by internal pressure so that the cap of the puparium is broken. Situated between the bases of the antennae is a small area known as the frontal lunule. The face, which is the area enclosed by the frontal suture, is laterally demarcated by the facial ridges. The lateral region of the head, the genae, is distinguished with the parafrontals or orbits along the inner border of the eyes and the jowls below the eyes. The dorsal border of the face forming the epistoma is hinged to the clypeus, which is usually a semicircular plate. The nature of the divisions of the head varies with different groups, but, in general, in most Diptera the whole of the anterior surface of the head appears to constitute the vertex and the frons is much restricted. In the tentorium, the body is reduced and there are three pairs of tentorial arms. The head carries several well-developed bristles, the number and arrangement of which are of classificatory value. Of importance are, facial, frontal, fronto-orbital, lateral facial, ocellar, vertical, vibrissae bristles and the arista.



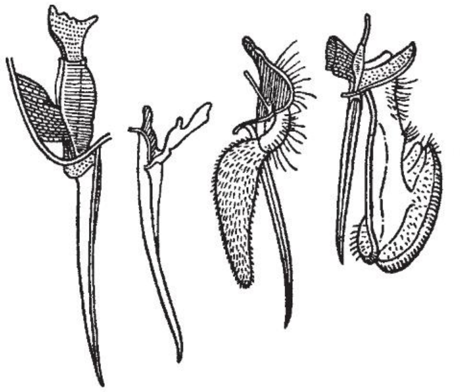
▲ **Fig. 64.1** *Head and mouthparts of housefly (Side view of mouth parts showing different parts. Medical Entomology, Macmillan)*

The antennae also show a great diversity of form, are important in classification and may be with 3 to 40 segments. It may be made up of a number of cylindrical segments as in the Nematocera or a smaller number of dissimilar segments. In the Brachycera there are two or three basal segments carrying a terminal flagellum-like jointed appendage, which may be very thin and slender and called the arista as in Cyclorrhapha or only attenuated and not very thin, and called the style. The arista may be plumose, pectinate or smooth.



▲ **Fig. 64.2** *Mouthparts of a horsefly—A. side view of head; B. mouthparts spread apart (ibid)*

The mouthparts (Figs 64.2 & 64.3) show profound variation and those of the mosquito have been discussed earlier. In the bloodsucking Nematocera and Brachycera they are adapted for piercing and are more or less blade-like or stylet-like, except for the labium and the palps. Usually the mandibles are distinct in the females, mostly atrophied in males. The grooved labium and the flattened hypopharynx form a close channel through which blood is sucked in. The labium is grooved dorsally and forms a closed sheath. The tabanids, however, have both mandibles and maxillae flattened and blade-like. In addition to forming a sheath for the mandibles and maxillae, the labium also serves for sucking up of liquid matter absorbed by the fine tracheae-like food channels or pseudotracheae of the labellae. In the Cyclorrhapha as exemplified by *Calliphora*, the maxillae are reduced and the proboscis consists of a proximal part, the rostrum, which bears the maxillary palps. The distal portion of the proboscis bearing the labium and hypopharynx is the haustellum, which is strengthened by a sclerotised plate, the prementum. A cuticular frame work called the fulcrum is also found in the rostrum. The labella contain a fine series of pseudotracheae or food channels, which are kept open by a number of sclerotised rings. These food channels open on the external surface of the labellar lobes and these in turn communicate with the oral aperture through the oral groove. The labella are extended and made turgid by blood pressure and numerous muscles help in the retraction of the proboscis while protrusion results from the distention of air sacs in the head region. In the bloodsucking species the proboscis is the main piercing organ and has a swollen, bulbous base. The haustellum is elongate and the proboscis cannot be contracted. In *Stomoxys* pseudotracheae are absent in the labella. The labrum and hypopharynx are short and so do not take part in penetration.



▲ **Fig. 64.3** *Mouthparts of Tabanus atralus (Snodgrass, 1935). Parts as in Fig. 64.2*

In the thorax, the mesothorax alone is well developed, the pro- and metathoraces being almost reduced to bands. Callosities are very characteristic of the lateral sides of mesonotum and the principal areas are- the prealar callus at the root of the wing, humeral callus at the anterodorsal angles of prescutum, and the postalar callus at the posterodorsal angle of the scutum. The pleural region is also well developed and consists of the mesopleuron, the area in front of the root of the wing, the pteropleuron below the root of the wing and sternopleuron above the anterior coxa, the metapleuron lying behind the pteropleura and the hypopleura, the region below the metapleuron and above the middle and posterior coxae. The chaetotaxy of the thorax, in particular the arrangement of the macrochaetae, are of significance in classification. In the legs, the tarsi are five-segmented and the pads of the feet vary in various groups, genera and species.

In the wings, the atrophy of the Cu and the vestigial nature of 2A and 3A are important. Otherwise they conform to the primitive hypothetical pattern and only the chief cross veins are present. In all Nematocera where Rs is three branched, R_2 and R_3 are distinct, while in the Brachycera where R_3 is also three-branched, R_4-R_5, are free. The free lobe, the alula and additional lobes, the squamae, are characteristic of most dipteran wings on their posterior margin. The halteres are almost always present and in *Drosophila* they are modified into miniature hindwings with distinct veins and have a base, the scabellum, bearing a stalk ending in a knob-like capitellum. The principal sensory structures are in the scabellum. The halteres are supposed to act as gyroscopic organs. The halteres of *Calliphora* contain specialised chordotonal organs.

The first abdominal segment is usually reduced and the number of segments varies in the different groups. In *Musca* segments two to five are clear, six to ten form the ovipositor; in tipulids 2 to 11 are distinct, but among the Cyclorrhapha the number is variable. In the fruit fly *Bactrocera*, all the eleven segments are distinct. Usually segments 9 and 10 are curved in the males and forms the hypopygium, with the genitalia.

The alimentary canal is more coiled in Brachycera, less so in Nematocera and highly complex in Cyclorrhapha, due to the coiling of the mid-intestine. The oesophagus divides into two branches, one entering the proventriculus which is absent in *Phlebotomus, Culicoides*, etc. and which when present may be of varied shape; the other branch enters the crop or food reservoir, wanting in hippoboscids, oestrids, etc. In *Musca,* it is a bilobed sac and in Culicidae there are three oesophageal diverticula. These food reservoirs serve as storage chambers for the nutrients sucked up. Their contents are later emptied into the midgut, which is a short sac in Nematocera. But the culicids have an elongate anterior region, the cardia, leading into a dilated stomach. The Cyclorrhapha have tubular midgut throughout and is extensively convoluted and divisible into an anterior part, the ventriculus and a posterior narrower proximal intestine. There are usually four malpighian tubules, the culicids with five and only two in culicoids. The midgut leads into the hind-intestine also usually divided into an anterior, distal intestine and a rectum. The salivary glands are also of varied size and shape, extending as long as the body as in muscids or up to the anterior part of the abdomen as in *Tabanus* or is trilobed as in *Culex.* Lying at the bases of the labellae are labial glands which help in moistening the surface of the labella.

The tracheal system is well developed and normally there are two thoracic and eight abdominal spiracles. In the Cyclorrhapha, well developed air sacs are present, which as in *Musca*, occupy more space than the other internal organs.

The nervous system is more highly modified, there being several variations between the single fused ganglion of the ventral nerve cord in the Muscoidea (Calyptratae of Griffiths) and the clear cut three thoracic and seven abdominal ganglia in the Nematocera. The dolichopodids are known to have two thoracic ganglia and the syrphids one thoracic and two abdominal ganglia. The maximum concentration of ganglia is seen in *Musca* and other Muscoidea, where the brain and the suboesophageal ganglion are closely fused to form a unit, while the thoracic and abdominal ganglia are intimately fused to form a compact mass in the thorax. A median abdominal nerve leads from this mass and gives off nerves to the various parts.

In the female reproductive system, the ovarioles are of the polytrophic type. In larviparous forms like *Glossina*, only a single ovariole is present. In *Hippobosca* two ovarioles are present. In oviparous Diptera the number is variable, ranging from five to over a hundred. In *Chironomus*, the ovary is very peculiar in that the numerous ovarioles branch off from a central axis. There are one to three spermathecae, generally dark, globular sacs lined with thick cuticle. The accessory glands are usually tubular and open dorsally into the common oviduct. In the larviparous *Glossina*, they serve to secrete a nutritive fluid, while in the oviparous forms the substance secreted enables the eggs to stick together when laid.

The testes in the males are usually ovoid or pyriform bodies, which are often pigmented. In the Hippoboscidae the testes form a compact mass of convoluted follicles. The testis leads into a short vas deferens uniting to form the ductus ejaculatorius. Associated with the ejaculatory duct is usually present an ejaculatory sac and one to many accessory glands; in *Musca, Chironomus, Phlebotomus* and *Tabanus* accessory glands are absent and the ejaculatory duct in *Musca* is long and convoluted. The male genitalia are frequently sunk in the abdomen in the Brachycera, but in some Nematocera and Cyclorrhapha the apex of the abdomen is curved downwards in varying degrees.

Myiasis is a common term used to describe infestation of dipteran larvae in man and animals. According to the nature and site of infestation, myiasis has been labelled to be cutaneous, oral, ocular, nasal, rhinal, gastric, intestinal, urinogenital, etc. The principal families of Diptera known to cause recognisable damage include Sarcophagidae, Calliphoridae, Muscidae, Anthomyiidae, Oestridae, Cuterebridae, Hypodermatiidae, Gasterophilidae and Syrphidae. Stray cases of acute myiasis have also been reported by individuals of Psychodidae (urinary myiasis) and Phoridae (ophthalmomyiasis).

Sarcophaga haemorrhoidalis is widely distributed and causes intestinal myiasis in man. The Calliphorid larvae usually attack fresh or decaying flesh and act as scavengers and some are always found associated with wounds of animals. *Chrysomyia bezziana* closely related to the screw worm mainly lives in wounds and ulcers and in India the larvae have been recorded from sores in nose, ear, vagina and eyes of man. *Calliphora erythrocephala* has been associated with human beings causing rhinal and intestinal damage. *Lucilia* with a number of known species causes “sheep strike”. The black blowfly *Phormia regina* is a carrion feeder, but may live on active sores of goat, sheep and occasionally man.

Interestingly enough, *Musca domestica* has been known to cause intestinal myiasis in man and the flies have been known to oviposit in the anal region of unclean infants. Among anthomyiids *Fannia canicularis* appears to be cosmopolitan causing intestinal myiasis and this has been reported from the urethra of males and females. Among oestrids. *Oestrus ovis* is the nasal botfly of sheep, the larvae growing in the sinuses and get sometimes sneezed out. They primarily infest goats and sheep; however, human infection causing painful conjunctivitis and nasal and throat troubles have been recorded.

The human warble fly *Dermatobia hominis* (Cuterebridae) has as principal hosts, the cattle, cat, dog and man. Their eggs are carried about by mosquitoes. The young maggots bore into the skin through the punctures made by the mosquito and lesions develop as typical boils or warbles within which the larvae thrive. Among the Hypodermatidae or the ox warble flies, *Hypoderma bovis* and *H. lineatus* are common and cause swellings on the back of cattle. Numerous records of human infection also exist. The botflies of horses or Gasterophilidae have *Gasterophilus nasalis* and *G. intestinalis* as common species.

Fly larvae when ingested by other animals like the fowl produce toxic effects. The lumber neck of chicken have at least been partly traced to feeding on fly larvae (like *Lucilia* sp.) and has been traced to botulism; the botulism producing organism breeds in dead meat on which the larvae have been feeding and help to transfer the same to chicken to produce a toxic effect.

Shortly after World War I maggot therapy in the disinfection of osteomyelities and infecting wounds was introduced. Larvae of *Lucilia, Phormia,* etc. were used to clean wounds which did not develop into sores. This, however, has only a historical interest now, because newer methods of infection control have been developed.

Three suborders are recognised in the Diptera - Nematocera, Brachycera and Cyclorrhapha.

SUBORDER NEMATOCERA

These diptera possess antennae longer than the head and thorax and are usually many segmented. Arista is wanting. The palpi are usually four or five segmented and are pendulous. Larvae possess a well developed exserted head and horizontally biting mandibles. The pupa is a free form except in some cecidomyiids.

SUBORDER BRACHYCERA

The antennae are shorter than the thorax and are generally three-segmented, the last being elongate. The arista or style is terminal when present. The palpi are one or two-segmented and porrect. The larva possesses an incomplete usually retractile head and vertically biting mandibles. The pupa is free except in Stratiomyidae.

SUBORDER CYCLORRHAPHA

The antennae are three-segmented with an arista, which is usually dorsal in position. The palpi are one-segmented. Head of larvae are vestigial. Pupation takes place in a puparium.

SUBORDER NEMATOCERA

Superfamily TIPULOIDEA

Family Tipulidae (daddy-long legs, crane flies)

This family includes some of the large sized forms commonly known as the crane flies or daddy-long legs. They have antennae bearing six to many segments and the front region of the head is extended forwards and in some forms an elongated proboscis is present. The mesonotum usually bears a V shaped suture and the legs are very long. The wings are often spotted. The larvae are amphipneustic and often aquatic with protrusible blood gills. The head is imbedded deeply into the prothorax. The labium is usually large and toothed and the hypopharynx generally sclerotised. The abdominal spiracles bear fleshy retractile processes. *Conosia irrorata* is an Indian species. Thirteen species of *Phyllobia* have been reported from the Himalayas.

Other families include Trichoceridae and Ptychoptreridae.

Superfamily PSYCHODOIDEA

Family Psychodidae (Moth-flies, Sand-flies)

Small moth-like insects with body and wings densely covered with hair, with long antennae composed of 15 or 16 segments. The lanceolate wings have the anterior cross vein closer to wing base. The bloodsucking sand-flies (Phlebotominae) are also included in this family. The females alone suck blood. Several species are known, but the well known ones are *Phlebotomus minutus, P. argentipes* and *P. papatasi*, the latter being the vector for kala-azar, caused by the flagellate protozoan *Leishmania donovani.* The bite of sand-flies is very vicious. During daytime they hide in corners or hangings and frequent cowsheds and stables. The females lay eggs singly or in clusters in cracks or crevices in the ground close to buildings or among heaps of organic matter. The larvae hatch in ten days, have a 12-segmented body, each segment with a transverse row of toothed spines. There are four instars, the first two with two and the rest with four long caudal bristles. The larvae feed on decaying vegetable matter and the duration is from three to eight weeks. The last larval skin mostly adheres to the pupa, which stage lasts from a week to ten days.

The other families included are Tanyderidae and Nymphomyiidae.

Superfamily CULICOIDEA

Family Dixiidae

Closely resembling the culicids in wing venation, but the wings are not scaled. Antennae elongate and with 16 segments. Larva metapneustic, aquatic. *Dixia maculata* is an Indian species.

Family Culicidae (mosquitoes)

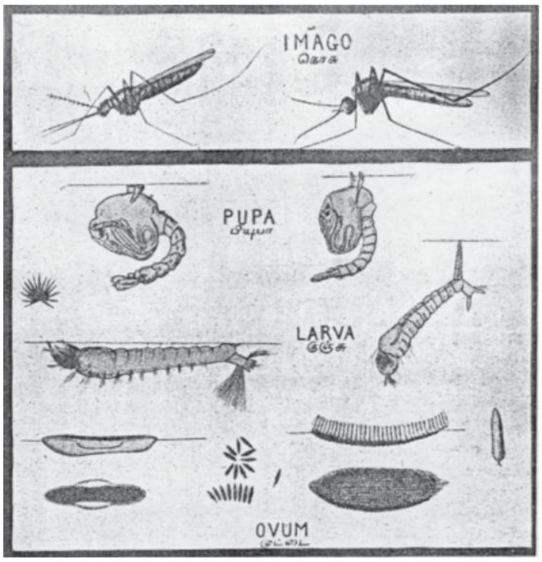
The mosquitoes, which are included in this family, exhibit sexual dimorphism—the females with antennae sparsely haired, while those of males carry conspicuous whorls of hairs. The second and fourth veins of wings are forked, while the third is unbranched and long. The anterior cross vein, unlike as in psychodids, is placed away from wing base. This includes the Anophelini or malarial mosquitoes and the Culicini or filarial mosquitoes, which are of considerable medical importance.

Among the anophelines, over fifty species have been recorded in India and as vectors of human malaria *Anopheles stephensi* and *A. culicifacies* are well known.

The culicini include the genera *Culex, Mansonia* and *Aedes*. The common house mosquito, a vector for filariasis is *Culex fatigans*, while that for yellow fever is *Aedes aegypti*.

Only female mosquitoes suck blood, while the males feed on nectar. Both the malarial and filarial mosquitoes are aquatic in the pre-imaginal stages, being passed in various kinds of pools, puddles, stagnant collections of water, etc. Eggs hatch in about 48 hours or a little more in the tropics, the larval stages last for about a week, and pupal stage for three to four days. Anophelines rest with the proboscis and the long axis of the body in a straight line but the culicine mosquitoes settle with abdomen parallel or inclined towards the surface on which it rests (Fig. 64.4).

The *Anopheles* and *Aedes* mosquitoes lay their eggs singly on or near the surface of the water, while *Culex* lays eggs collectively to form a compact mass or egg raft. The eggs vary in shape, being boat shaped with a float on either side in *Anopheles*, while in *Culex* they are fusiform; in *Aedes* they are ovoid and around it are a series of small air chambers helping in floating. The larvae of mosquitoes are called the wrigglers, which possess a well developed head carrying dense tufts of long hairs of feeding brushes over the mouth. The thorax is made up of a single fused segment and behind it are nine abdominal segments. Surrounding the anal segment are four tracheal gills. The habits of the larvae of *Anopheles, Culex* and *Aedes* are distinct. In *Anopheles* the respiratory opening is on the ninth segment and the larva remains parallel to the surface of water with the aid of special hairs called palmate hairs. In *Culex* there is a respiratory siphon on the ninth segment on the apex of which is the respiratory opening. The larvae hang head downwards inclined at an angle, the apex of the siphon being in contact with the surface. *Aedes* on the other hand is a bottom feeder. The pupae of mosquitoes called the tumblers are characterised by an enlarged cephalothorax on which are a pair of respiratory trumpets. The abdomen is tucked underneath the cephalothorax.



▲ **Fig. 64.4** *Life history of mosquito: Left-Anopheline mosquito; Right-Culicine mosquito (after T. V. R. Ayyar, 1940)*

A major debilitating disease associated with mosquitoes is malaria. *Anopheles* has several species involved in malaria transmission: *A. culicifacies, A. fluviatilis, A. leucosphyrus, A. maculatus, A. philippinensis, A. stephensi,* and *A. varuna* in India; *A. culicifacies* and *A. maculatus* in Sri Lanka; *A. mangyanus, A. minimus* in the Philippines and Indonesia; *A. fluviatilis, A. maculatus* and *A. sundanicus* in Thailand, etc., are well known. The use of DDT for control purposes, and development of antimalarial drugs like chloroquine and primaquine and thorough knowledge of anopheline biology have gone a long way in eradicating malaria the world-over.

A number of arthropod-borne viruses (arboviruses) are transmitted by mosquitoes. Chikungunya virus producing the terrible joint afflictions in man has been isolated in Africa from *Aedes*, Mayaro virus of Trinidad producing Brazilian lethal illness from *Mansonia*, joint-breaker disease virus (or the O'nyong-nyong) from *Anopheles* and yellow fever virus of South America from *Aedes aegypti* are examples.

Filarial nematode transmission (of the worm *Wuchereria bancrofti*) has been effected by mosquitoes. *Culex* and *Mansonia* are two genera involved in this transmission in India.

Family Blephariceridae

These are elongate flies with long legs, confined to hilly areas and breeding in the clear waters of swift running hill streams. The larvae hold on to submerged stones. The females are predaceous on small Diptera. The larval body consists of head, thorax and the first two abdominal segments fused together, the remaining segments being incised laterally. A longitudinal row of median ventral suckers are present on the abdomen.

Family Deuterophlebiidae

These are popularly called the mountain midges and several species of *Deuterophlebia* have been recorded from the Himalayas. These are very much like ephemerids with large wings, which are finely pubescent. The antenna is six-segmented, thin and very much longer than body. Mouthparts and ocelli are absent in the adult. The larvae and pupae breed in the clear water of torrential mountain streams. Special organs of anchorage in the form of stout lateral prolegs armed with circlets of hooks are present in the larvae. The apex of the abdomen bear blood gills.

Family Chironomidae (midges)

Small mosquito-like delicate flies commonly called gnats or midges, with antennae plumose in males and pilose in females, 6 to 15 segmented. Wings are not scaled. Mouthparts are poorly developed; legs are long and slender; head small, often concealed by the thorax. The adults are abundant near lakes, ponds and streams and appear before sunset in swarms. The larvae are aquatic and with two pairs of elongate blood gills on eleventh segment and two pairs of papillate anal gills. The larvae are called blood worms because they are reddish, due to the presence of haemoglobin in the blood. Chironomids lay eggs in a mass covered over by a transparent mucilaginous substance. Some larvae inhabiting the surface are green. The larvae usually live in tubes, free or attached to some substratum. The tubes are made up of mud or leaf particles. Pupae usually float in water or lie at the bottom. There are a pair of respiratory filaments which are branched.

Chironomus vicarius, C. cubicularum and *C. socius* are the common Indian species.

Family Ceratopogonidae (biting midges)

These are the biting midges and include many bloodsucking forms. The head is not concealed by the thorax and the antennae are pilose in the females and plumose in the males and are 12 to 15 segmented. The mouthparts are adapted for piercing. Ceratopogonids are predatory as adults and suck the blood of vertebrates, including cattle. Of the Indian genera, *Ceratopogon, Culicoides, Leptoconops, Forcipomyia,* and *Brachypogon*, the first two are most common. *Ceratopogon* is sluggish, covered with spines all over the body and with leg-like appendages. They breed in kitchen refuse, decaying leaves, etc. The females are bloodsuckers, burrowing into the hairy coat of cattle and get gorged with blood. Larvae are not strictly aquatic, living on edges of ditches in refuse and become fully grown up in two weeks. Pupae have long anterior spiracles and a pair of spinous hemispherical protuberances on head. *Culicoides* is of veterinary and medical importance, 1 to 1.5 mm long, dark brown, with 15 antennal segments. Their wings are often hairy and marked with spots or circles. All species of *Culicoides* breed in water or are semi-aquatic. The larvae are small, with the last abdominal segment bearing spines and bristles and four retractile tracheal gills which are cleft. *Culicoides pattoni* and *C. macrostoma* are common species.

Family Simuliidae

This family includes the "buffalo gnats," which are thick, dark flies, 3 to 6 mm long, with short, stout legs and long mandibles. The females have dichoptic eyes, while they are holoptic in males. Antennae are 9 to 11-segmented, without hairs in both sexes. These flies have a hump-backed appearance due to the convex meso-notum. The wings are large, broad with stout anterior veins, the rest are weak. The males usually have the first tarsal joint swollen. Characteristic structures called calcipala, a flap on the inner side of the apical end of the second basitarsus of hindleg and pedisulcus, a notch on the dorsal side of the second tarsal segment are present.

Simuliids bite both mammals and birds and frequently appear in swarms. They bite the ears and udders of cattle and inside the ears, causing chronic inflammation of the affected parts and irritation. Blood oozes out through the punctures and bleeding wounds caused by several punctures cause death of cattle. *Simulium damnosum* transmits *Oncocerca volvulus* in Africa.

Simuliids are aquatic in the early stages and usually inhabit swift flowing streams and their larvae are adapted to live in well aerated water. Females deposit over 500 eggs in batches, on leaves, blades of grass and the eggs are covered with a gelatinous substance. The incubation period is about a week. The larvae are cylindrical, enlarged posteriorly and narrowed in the middle. The head is large, with a pair of eyes, pair of antennae and two conspicuous fan-like appendages provided with hairs, serving as brushes for procuring food. The thorax is non segmented and carries a forwardly directed prolet in the form of a conical process. The abdomen is nine- segmented and terminates in a sucker used for anchoring itself on its support. The larva changes position by a looping movement. From the rectum protrudes three sausage-like structures called the blood gills. The larvae also possess two pairs of spiracles on thorax and eight pairs on the abdomen. There are six to seven instars, the larvae usually live for four to five weeks, the last larva spins a silken cocoon and pupates. *Simulium striatum* is common in Southern India, while *S. indicum* and *S. grisescens* arc found all over the country.

The other family recognised is Thaumaleidae.

Superfamily ANISOPODOIDEA

A single family Anisopodidae is recognised.

Superfamily BIBIONOIDEA

Family Bibionidae

This family includes generally robust flies with antennae eight to 16-segmented, with antennal segments bead-like and closely apposed. Wings large and with anterior veins strikingly prominent. Males with holoptic eyes. Adults occur in grassy vegetation or decaying vegetation and larvae are gregarious. The larvae of *Bibio* are the most primitive of dipteran larvae. *Bibio obscuripennis* occurs in India.

The other families recognised are Hyperoscelidae and Pachyneuridae.

Superfamily MYCETOPHILOIDEA

Family Mycetophilidae (fungus gnats)

These are popularly called the fungus gnats. Small delicate flies with long filiform antennae made of 12 to 17 segments and lacking whorls of hair in the males. Body is elongate and adults are mostly black, brownish or yellowish. Thorax is mostly arched, coxae of legs are elongate and tibiae with spurs. Adults inhabit damp or dark places with abundant fungal growths or decaying vegetation. They leap well, the hind limbs being long and adapted for it. The larvae are smooth and vermiform, feeding on fungi and gregarious in habit. Some forms like *Sciara* and *Mycetophilia* are serious pests of edible mushrooms. *Sciara rufithorax* and *Platyura venusta* are common Indian species.

THE SCIARID FLY *Bradysia tritici*

It is the most important pest of white-button mushroom during February-April in the Punjab and up to 32.7% infestation in the crop is noticed. The damage at button formation stage causes total loss of the infested mushroom. Incorporation of 50 ppm chlorpyrifos or 50 ppm pririmiphos methyl in the compost and casing has been found effective. When the flies are noticed on mushroom beds, window panes, walls and ceiling of the mushroom house, spray dichlorvos 30 ml/sq. m. of space in fine droplets. After spraying close the doors and windows for 2 hours. Avoid direct spraying of beds. Stop application of insecticide 48 hours before picking of mushrooms.

Family Cecidomyiidae (gall midges)

These are minute delicate insects with relatively long antennae and legs. The antennae are of moniliform type adorned with conspicuous whorls of hair. Ocelli are present or wanting. The venation is greatly reduced to a few longitudinal veins, which are not branched for the most part. Cross-veins are absent. Coxae are not elongated and tibial spurs are absent. The larva is white, yellow, orange or bright red and occasionally brown in colour, peripneustic with a reduced head. It is somewhat narrow at both extremities and is characterised by the presence of a sternal spatula or "breast-bone" mid-ventrally on the prothorax. The phenomenon of paedogenesis is known in some cecidomyiids such as *Miastor* and *Oligarces.*

These insects show great diversity in their habits. A few are predaceous or parasitic on other insects (aphids, coccids, larvae and pupae of some flies, etc.) or may breed among the excrement of tipulids and caterpillars, under bark of trees, fungi or decaying vegetable matter. In India, *Schizobremia malabarensis* on *Ferrisia virgata* and *Diadiplosis indicus* on *Phenacoccus hirsutus* and *Pseudococcus corymbatus* are predaceous. The midge *Mycodiplosis indica* feeds on the rust spores on *Pennisetum typhoideum. Rubsaamenia artocarpi* and *Camptomyia artocarpi* from decaying fruit of *Artocarpus heterophyllus* and *C. ricini* from decaying shoots and capsules of castor are some saprophagous species. Many are phytophagous and damage the plants in various ways. Majority of the species produce galls on various parts of plants. The species of midges found to be inquilines in the galls produced by Coleoptera, Tephritidae and other cecidomyiids are known as gallicolous forms. Others live in the spikelets of Gramineae, flowers of Compositae, in fruits, etc.

Among the phytophagous species the wheat hessian fly *Phytophaga destructor* in North America and New Zealand and the Pear midge *Contarinia pyrivora* in Europe are well known. In India a large number of species of midges are known to attack a variety of plants in various ways. Galls on shoots of bamboo are caused by *Meinertomyia inaequipalpis.* In *Boerhaavia* sp., the leaf buds are damaged by *Neolestremia boerhaaviae.* Galls are produced on leaflets by *Lobopteromyia bivalviae* in *Acacia catechu* and by *L. ramachandrani* in *Acacia suma.* On mango, galls are produced on leaves by the midges *Alassomyia tenuispatha, Amradiplosis amraemyia, A. brunnigallicola, A. keshopurensis, A. viridigallicola, A. echinogalliperda, Procantarinia matteiana,* etc. Galls are produced on midribs and veins of leaves of *Ficus religiosa* by the midge, *Pipaldiplosis pipaldiplosis.*

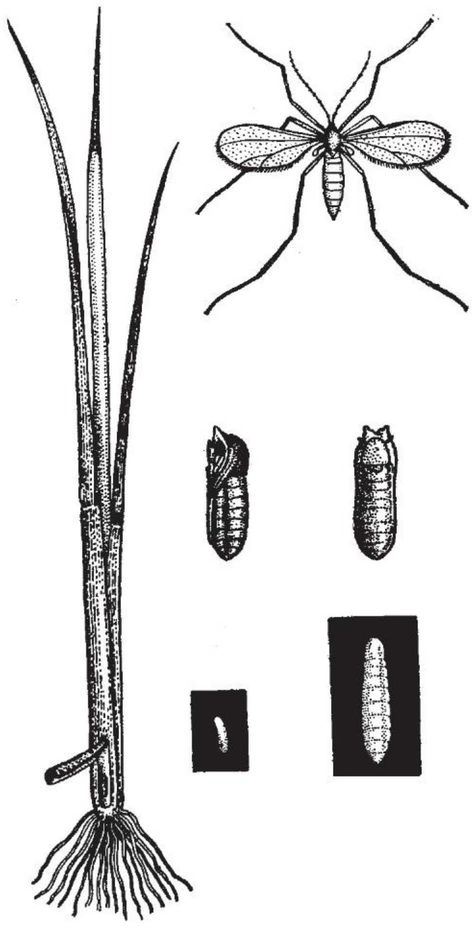
The midges *Lasioptera falcata* and *Lasioptera cephalandrae* produce galls on stems of *Momordica charantia* and *Coccinia indica* respectively. The silver shoot or tubular gall in rice produced by the midge *Orseolia oryzae* is nothing but the modified leaf sheath. The spikelets of sorghum are damaged by the well known sorghum midge *Stenadiplosis sorghicola.* The mango inflorescence rachis is severely damaged by the midge *Erosomyia indica.* Flower buds are also attacked by midges as in mango by *Procystiphora mangiferae* and *Dasineura amaramanjarae* and in *Moringa oleifera* by *Stictodiplosis moringae.* Flower buds and developing fruits of *Sesamum indicum* and *Ricinus communis* are infested by the midges *Asphondylia sesami* and *A. ricini,* respectively. Galls are formed on the roots of *Eletteria cardamomum* by the midge *Hallomyia cardamomi.*

The following are some species which are of considerable importance as pests of cultivated crops and fruit trees in India.

1. THE RICE GALL MIDGE *Orseolia oryzae* (Fig. 64.5)

The insect is distributed in Myanmar, Cambodia, Sri Lanka, China, India, Indonesia, Nigeria, Northern Cameroons, Sudan, Thailand and Vietnam.

The symptom of attack is the formation of the leaf sheath into a hollow, dirty white or pale green, pink or purple, long cylindrical tubular gall bearing at its tip a small atrophied leaf blade complete with ligules and auricles. The gall is known as "silver shoot" or "onion shoot". After the emergence of the adult midge the gall dries up and disintegrates. The infestation can take place in the nursery itself and early infestation results in formation of galls from tillers, which consequently do not bear panicles. Heavy infestation may result in loss up to 50 per cent in the crop.



▲ **Fig. 64.5** *Orseolia oryzae (T.B. Fletcher, 1914)*

The adult fly is yellowish-brown, mosquito-like and is 3 to 3.5 mm long. They are active at night. The female lays 100 to 300 eggs singly or in groups of two to six on the hairs of ligules of the rice leaf or on the leaf sheath just below or above the position of ligules. Occasionally they may be laid on standing water. The egg is reddish, elongate, tubular and 0.55 mm long with rounded ends. The incubation period is from three to four days. The first instar larva that hatches out on the leaf moves down in about six to twelve hours to the shoot apex without boring into plant tissue. Once it reaches the shoot apex, throughout its development it feeds at the base of the apical meristem. If more than one larva reaches the shoot apex only one will survive to maturity. Due to larval feeding the apical meristem gets suppressed and induces formation of radial ridges from the innermost leaf primordium, just above the level of the posterior end of the larva, which is followed by the elongation of the leaf sheath. If the first or second instar larva dies during the course of its development, the apical meristem gets reactivated and resumes development into a normal shoot. But such a phenomenon does not occur if the larva dies in its later stages of development. It appears that the development of the radial ridges can be attributed to diversion of nutrients from the apical meristem to the larva, and the subsequent gall elongation possibly to substances produced by the first instar larva and pre-pupa. Normal development of the larva proceeds only if the first instar larva infests a growing shoot apex and development is inhibited if it attacks an inactive axillary shoot apex. In cases of severe outbreak, though almost all shoot apices are infested, due to larval dormancy there is a staggered development of gall and adult emergence. The pest carry over to the next season is accomplished by the larvae remaining dormant in active axillary shoot apices of host plants. The full grown larva is 3 mm long and pale red in colour. It pupates at the base of the gall. The pupa with the help of several rows of backwardly pointed subequal abdominal spines wriggles up the gall to its tip, makes a hole with its spines at the anterior end and projects half way out, and then the adult emerges, usually during the night.

Apart from rice, the midge also breeds on *Cynodon dactylon, Eleusine indica, Ischaeum ciliare, Panicum* sp., *Paspalum scrobiculatum,* etc.

Control: The larvae are parasitised by the parasitoids *Platygaster oryzae, Polygnotus* sp. (Platygasteridae) and *Propicroscytus mirificus* (Pteromalidae). Other parasitoids include *Neanastatus* sp., *Proleptacis oryzae* and *Telenomus israeli.* The rice varieties *Ptb 18* and *Ptb 21* (ptb–Pattambi) are resistant to gall midge attack. Five biotypes of gall midges have been observed.

Seed treatment with chlorpyrifos 0.2% emulsion for 3 hours or mixing seeds with either chlorpyrifos (0.75 kg a.i./ 100 kg seed) or imidacloprid 0.5 kg / 100 kg seed) provides protection for 30 days in the nursery. Effective granular insecticides at 1 kg a.i. /ha applied in standing water are fenthion, diazinon, chlorpyrifos, quinalphos and phorate, and at 0.75 kg a.i./ha is carbofuran. Fipronil and imidacloprid are also promising. Seedling root dip in 0.02% chlorpyrifos emulsion before transplanting for 12-14 hours gives protection for 30 days.

2. THE SORGHUM MIDGE *Stenadiplosis sorghicola* (Fig. 64.6)

The sorghum midge occurs in the USA, South America, West Indies, Africa, Asia, Australia and Italy.

The insect is considered to be one of the most widely distributed and important pests of sorghum. In India, although generally its incidence is somewhat sporadic, of late, with the large scale cultivation of hybrid sorghum it has become a serious pest. Due to infestation the grains fail to develop and in cases of severe attack the whole head may be damaged resulting in significant loss in the production of sorghum. The midge is more serious in low-lying areas where relatively high atmospheric humidity prevails during the growing season. In the field, the severity of infestation is further dependent on the initial infestation and subsequent build up in the crop, as also the length of time during which flowering sorghums are present in an area. The loss caused by the insect ranges from 20 to 50 % in the crop.

The adult is a tiny, fragile, mosquito-like insect with a bright orange abdomen and a pair of transparent wings. They mate soon after emergence from pupae and start laying eggs shortly. It lays the eggs singly within the spikelets of sorghum when the pollen is being shed. The maggots feed on the ovaries and destroy the developing grains and pupate within the damaged spikelets. The life cycle from egg to adult occupies 17 to 19 days. Adult lives for one or two days. The carry over from one season to the next is accomplished by the larvae which diapause in crop debris or on wild hosts.

In West Africa *Sorghum membranaceum* is resistant to this insect as its long papery glumes are not forced apart at anthesis, which makes it difficult for the midge to oviposit in the spikelets.

In India it is parasitised by *Tetrastichus coimbatorensis*. Two or three applications of carbaryl or endosulfan at intervals of 7 days commencing at 90% earhead emergence afford protection.

▲ **Fig. 64.6** *Sorghum gall midge: Top- Midge on florets; Bottom-Affected ear*

3. THE MANGO INFLORESCENCE MIDGE *Erosomyia indica*

This is the most important species of the midges that attack mango inflorescence in India. The insect is distributed throughout India. It attacks the inflorescence at the bud stage, elongating axis of the inflorescence and small developing fruits. The damage inflicted by the pest is often serious. The growth of the inflorescence is stunted and the buds do not open. The infested fruits turn pale, become shapeless and drop after the larvae jump out of them. It also produces galls on midrib of leaves and petiole.

The midges mate soon after emergence. The insect is small and yellowish in colour. It lays elongate oval creamy white eggs at the base of developing fruit or on the dorsal surface of leaf near the base or on the inflorescence peduncle. The incubation period is three days. The larvae feed on floral buds, axes of inflorescence and newly set fruits. They become full grown in eight to ten days. When the food availability is reduced, the larvae enter diapause in the soil at about 2 cm depth and remain in this stage till the next mango season when they pupate and emerge as adults.

4. THE MANGO BLOSSOM GALL MIDGE *Procystiphora mangiferae*

It is found throughout India on mango. The larvae feed on the contents of floral buds and cause conical gall-like structures. They dry up in course of time and drop down.

The light orange coloured adult fly lays one to three elongate cylindrical eggs between the calyx and corolla of the bud. The incubation period is 30 to 36 hours. The yellowish full grown larva pupates within the bud in a thin silken cocoon; sometimes two or three pupae .may be seen in a bud. The empty pupa remains attached to the bud. Its life cycle lasts 12 to 14 days.

5. THE MANGO BLOSSOM MIDGE *Dasineura amaramanjarae*

This insect is widely distributed all over India. The larvae feed on the contents of floral buds which fail to open and drop down ultimately resulting in poor fruit setting.

The flowering in mango coincides with the emergence of adult midges. The larvae of previous year diapausing in the soil pupate with the mango flowering season and emerge as adults. The midges mate soon after emergence and insert the eggs into mango flower buds, at three to six eggs per bud. A female lays 40 to 50 eggs on 21 to 40 buds. The egg is stalked and creamy white in colour. The incubation period is 30 to 36 hours. The orange red larva wriggles out of the bud and drops down. The larval period is 10 to 13 days. It pupates in the soil at 4 to 8 cm depth in a cocoon of silk with sand particles adhering to it, and emerges as adult in four to six days. Towards the end of the season the larvae are seen at a depth of 15 to 18 cm in the soil and enter diapause.

6. THE CITRUS BLOSSOM MIDGE *Dasineura citri*

The insect infests the blossom of many varieties of citrus in Punjab, Maharashtra, Karnataka, Andhra Pradesh, Kerala, Bengal, Assam and Sikkim. .

The infested blossom begins to gape on one side, becomes irregular in shape and drops easily when touched.

The orange-coloured minute fly inserts the stalked eggs in between the petals of a small bud. The incubation period is 32 to 40 hours. In a bud a maximum of 66 larvae can be seen. There are four larval instars, the larval period being 10 to 12 days. It pupates in a silken cocoon in the soil. The pupal period is four to six days. After the flowering season the larvae diapause within silken cocoons in the soil. With the advent of next flowering season, they pupate and emerge as adults. The incidence is usually heavy during February-March.

7. THE SESAMUM GALLFLY *Asphondylia sesami*

This insect is one of the important pests of gingelly in India. The adult fly inserts its eggs into flower buds. The larvae feed on the ovary. The feeding causes malformation of pods which get shrivelled up and do not set seeds. Heavy infestation results in serious loss of gingelly seeds. The larva pupates inside the malformed gall-like structure of the pod and emerges as adult.

Application of carbaryl 10 % dust thrice at 35th, 50th and 65th day from sowing at 20 kg/ha is suggested.

8. THE MORINGA BUD MIDGE *Stictodiplosis moringae*

The insect is small and brownish black. The female inserts its ovipositor inside the bud and deposits the eggs in clusters on the anthers. In a single bud 5 to 80 eggs are seen in clusters. The larvae hatch out from the eggs in 24 to 31 hours. They feed on the internal contents of the buds which drop down to the ground. The larval period is six to nine days. It pupates in the soil and emerges in five to nine days. The development period from egg to adult is 12 to 19 days. The pest is prevalent on *Moringa oleifera* throughout the year but serious infestation occurs during October-January.

SUBORDER BRACHYCERA

Superfamily TABANOIDEA

This includes the families Rhagionidae, Tabanidae, Xylophagidae, Pelecorhynchidae and Stratiomyidae.

Family Rhagionidae

Predaceous flies with elongate weak pilose bodies, non-annulate third antennal segment and the tibiae mostly with spurs. Wing veins unlike in stratiomyids are not concentrated in the costal region and squamae almost absent. Larvae carnivorous, feeding on other insects. *Rhagio* sp.

Family Tabanidae (horse flies)

This is a very large family of Diptera, including the "gadflies" or horse flies. They have very large eyes, being contiguous or holoptic in males and dichoptic in females. They have large heads and stout bodies, the eyes usually having golden green and purple marks when alive. Callosities are present on the frontal portion of the head. Antenna is three-segmented, segment third is annulate, arista absent. The family includes over 2000 species.

The female tabanids are usually bloodsucking, the males feeding on nectar of flowers. The females are exclusive parasites of warm blooded animals, hosts being horses, cattle, buffaloes and rarely man. Some species attack very specific sites for bloodsucking as for instance *Tabanus speciosus* and *T. rubidus* settle down on the lower parts of the back and hindleg, *T. striatus* on underside of abdomen, and *T. macer* on neck and abdomen of cattle. Tabanids deposit their eggs in masses on vegetation, logs of wood, overhanging water and their larvae are aquatic. Eggs are usually cemented together by a thin substance, with 300 to 600 eggs in a cluster. The larvae hatch in four to seven days, are twelve segmented, white, their head pointed, retractile and body tapering posteriorly. Segments 3 to 11 are furnished with tubercles on the dorsum, sides and venter. The larvae are carnivorous and cannibalistic with seven to eight moults normally. The larvae of larger tabanids have air sacs connected with tracheal tubes and are good swimmers. The larval period is variable, varying with species.

Tabanids function as vectors of disease producing organisms. Anthrax caused by *Bacillus anthracis* in domesticated mammals and man, tularaemia fever of man in America, trypanosomiasis, loaiasis (by *Loa*) are examples.

Family Stratiomyidae

These include small to large, almost flattened, bristleless flies with annulate third antennal segment; a conspicuous scutellum is present. They occur in damp or moist areas and wings with veins more crowded near costa. Larvae are terrestrial or aquatic and carnivorous or saprophagous. Pupae remain enclosed in larval skin. Some of the Indian species are *Sargus metallicus, Stratiomyia barca, Cyphomyia indica* and *Clitellaria heminopla.*

Superfamily ASILOIDEA

This includes the families Therevidae, Scenopinidae, Mydidae, Apioceridae, Nemestrinidae, Acroceridae, Asilidae and Bombyliidae.

Family Asilidae (Robber flies)

Asilidae are commonly found in all sorts of places and are moderate to large sized bristly flies with horny piercing type of mouthparts and powerful, prehensile legs adapted for catching the prey and piercing its body. A tuft of hairs and protruding eyes are very characteristic of these robber flies. The leg ends in a bristle-like empodium and large pulvilli. Other characteristic features are protuberant eyes having a hollowed out space between the eyes on the top of the head and more or less bearded face. These insects are important as they are predaceous on a variety of insects such as grasshoppers, beetles, wasps, bees, dragonflies, other flies, etc. and their powerful forelegs adapted for grasping the prey. The larvae of Asilidae live in soil, sand, wood, or in leaf-mould and may be either predaceous or scavengers.

Some of the species noticed in India are *Allocotosia aurata, Hyperechia xylocopiformis* and *Philodicus femoralis.*

Family Nemestrinidae

Large flies with simple third antennal segment and mouthparts with very long proboscis, frequently many times longer than the body. These flies frequent flowers to suck nectar.

Hirmoneura annandalei, and *H. brunnea* are Indian species.

Family Bombyliidae (Bee flies)

These flies popularly called the bee flies are with robust, densely pubescent bodies. Legs are very long and slender; proboscis generally very long, often projecting forwards. Males with holoptic eyes. Wings show often reduced venation, with well developed squamae.

Larvae are usually parasitic or predaceous on grasshopper eggs and beetles, or on smaller insects. Adults feed on nectar of flowers. *Bombylius* is a common cosmopolitan form.

Superfamily EMPIDOIDEA

This includes the families Empididae and Dolichopodidae.

Family Empididae

These are predaceous flies, without metallic sheen, feeding on small insects including the Diptera and with a well developed downwardly projecting horny proboscis, used for piercing. They look very much like asilids, but lack the facial cluster of hairs. Legs often show differences in the two sexes, the males often with thickened femora, tibia or tarsi. Larvae live in the soil, among decaying vegetation. *Empis* is a typical genus.

SUBORDER CYCLORRHAPHA

The following two sections are recognised.

Section I ASCHIZA

These are dipterans characterised by absence of frontal suture and ptilinum. The frontal lunule is often indistinct or wanting. The elongated cell Cu (except in Phoridae) extend more than half-way to wing margin.

Section II SCHIZOPHORA

These insects are characterised by distinct frontal suture and lunule and presence of ptilinum. The cell Cu is short or vestigial (except in Conopidae).

Section I ASCHIZA

Superfamily LONCHOPTEROIDEA

This is represented by a single family Lonchopteridae.

Superfamily PHOROIDEA

This includes the families Sciadoceridae, Ironmyiidae, Phoridae, and Platypezidae.

Platypezidae is represented by a common species *Platypeza argyrogyna* in India.

Family Phoridae (hump-backed flies)

Phoridae are small or minute, greyish-black or yellowish flies characterised by hunched thorax, which gives a hump-backed appearance, heavily developed anterior veins on forewings and laterally flattened hind femora. The wings are often vestigial or wanting. These insects are abundant in decaying vegetation. The larvae live in decaying animal or vegetable matter. Some forms are known to live in fungi. Some species are parasitic on other insects. A few are known to be either inquilines in the nests of ants and termites or parasitic on ants and millipedes. The flattened larvae sometimes possess a breathing tube at their tail end and the pupa has two thoracic breathing tubes or processes. The sexes are separate but *Termitoxenia*, which inhabits termite nests, is said to be hermaphrodite. In India, *Chonocephalus fletcheri, C. depressus* and *C. similis* occur in decaying vegetable matter. *Clitelloxenia marshalli* and *Indoxenia flavescens* are found in termite nests in Bangalore. The phorid *Megaselia scalaris* is a parasite of *Amsacta albistriga* and *Azygophleps scalaris* in South India. *Megaselia sandhui* attacks white-button mushroom *Agaricus bisporus* in the Punjab. In India, *Aphiochaeta xanthina* is of veterinary importance as it is known to cause myiasis in livestock.

Superfamily SYRPHOIDEA

This includes the families Pipunculidae and Syrphidae.

Family Pipunculidae (big-headed flies)

Pipunculidae are small flies with a mobile, subhemispherical, very large head composed mostly of eyes. A long dorsal arista is present on the antenna. These insects are chiefly parasitic on leaf hoppers and fulgorids and hence are of some importance. *Pipunculus* and *Verrallia* are two common genera in India. *Pipunculus annulifemur* is a nymphal parasite of the mango hoppers.

Family Syrphidae (Hover flies)

It is a large family comprising of moderate to large-sized flies which are often brightly coloured and some resembling bees or wasps. The presence of a spurious vein between the radius and the media of the wings in most cases is characteristic of the family. In their habits the larvae exhibit extreme variations. Many are predaceous on aphids and other homopteran nymphs. Some are inquilines in the nests of ants, termites and bees and others inhabit decaying vegetation and rotting wood. A few which are found in polluted aquatic habitats are called as rat-tailed maggots as they have a very long breathing tube. These are sometimes injurious to man as they are responsible for intestinal myiasis. A few are phytophagous as external feeders on plants or as internal feeders in bulbs. They may feed within stems or in fungi.

Syrphus confracter, S. serarius, S. balteatus, S. isaaci, Sphaerophoria javana, S. scutellaris, Xanthogramma scutellare and *Paragus serratus* are some syrphid flies predaceous on aphids in India. The syrphid *Baccha sapphirina* is predaceous on psyllids. *Syritta pipiens* is found in rotting paddy and ashgourd.

Aphidophagous Syrphids

1. *Syrphus balteatus* DeG: The adults mate for 25 minutes and the pre-oviposition period is three days. Eggs are laid over a period of two to four days singly on mustard plant parts infested with the aphid *Lipaphis erysimi*. Egg is white, oval, sculptured with parallel small white stripes, interrupted by depressions. Incubation period is four five days. The larva is characterised by its typical semi-looping movement. The larva fixes its anal end with the substratum and raises the anterior portion of the body upward, and sucks the body fluid of the prey making it helpless. Fully developed third instar larva is 11 mm long and the body is covered with minute scales. The larval period is about 10 days. It pupates on the substratum itself and the pupal period varies from 9-11 days.

2. *Syrphus confracter* Weid.: This is also associated with *Lipaphis erysimi* and most effective of the syrphid predators noticed on this aphid. The larva measures 17 mm long and the larval and pupal periods being respectively, 12 and 13-16 days.

3. *Ischiodon scutellaris* (Fab.): It also feeds on the aphid *L. erysimi*. The larva is 12.5 mm long and the larval and pupal periods being respectively, 10-11 and 9-13 days.

Section II. SCHIZOPHORA

In this section the following important families are considered and the old major groups in vogue are no longer useful.

Superfamily LONCHAEOIDEA

This includes the families Lonchaeidae and Cryptochaetidae.

Family Cryptochaetidae

The flies are characterised by having a short spine or tubercle instead of an arista on the enlarged third antennal segment which reaches nearly the lower edge of the head. The flies are attracted to the eyes of man and thus annoys him by entering his eyes. The larvae are parasitic on coccids. *Cryptochaetum iceryae*, a well known parasite of the fluted scale *Icerya purchasi*, was introduced into California from Australia. The parasite is prevalent on the same host in South India.

Superfamily LAUXANIOIDEA

This includes the families Lauxanaiidae, Celyphidae, Chamaemyiidae and Braulidae.

Family Chamaemyiidae

The flies are minute, grey, sometimes with black spots and are predaceous on aphids and coccids. In India, *Leucopis luteicornis* is predaceous on the cotton coccid *Pseudococcus* sp. The aphids *Aphis gossypii, Macrosiphum granarium* and *Myzus persicae* are preyed upon by *Leucopis griseola.*

Superfamily DROSOPHILOIDEA

This includes the families Drosophilidae and Ephydridae.

Family Drosophilidae (pomaceflies or fruitflies)

Drosophilidae are small yellowish flies with red eyes. The larvae of most species feed on decaying fruit and fungi and a few mine into leaves or fruits. Some are predaceous on aleyrodids and coccids. The larvae of the fly *Acletoxenus indicus* are predaceous on the aleyrodids *Trialeurodes ricini*, *Siphoninus phillyreae, Aleurocanthus spiniferus*, etc. In India, *Gitona distigma* infests the tender fruits of *Moringa oleifera*. *Drosophila melanogaster* is the common fruitfly used in genetic studies. *Drosophila montium* infests berries of lantana. *Gitonides perspicax* is predaceous on the mealy bug *Saccharicoccus sacchari* found on sugarcane.

Family Ephydridae (shoreflies)

Ephydridae are small, black or darkly coloured, long legged flies found in marshy and damp places. The larva of *Psilopa petrolei* is known to live in pools of crude petroleum in California. The larvae are mostly aquatic and are found in decaying vegetable matter, saltish or brackish pool, etc. A few are either phytophagous or predaceous on eggs of spiders. Species of *Hydrellia* are known to mine into leaves of rice and inflict damage to the crop. *Hydrellia griseola*, *H. incana*, *Ephydra macellaria* and *E. riparia* are some species known to infest rice in different parts of the world. In India, *Hydrellia philippina* and *H. sasakii* are known to attack rice.

THE RICE WHORL MAGGOT *Hydrellia philippina* Ferina

It was first noticed in 1963 and is an important pest of rice in Andhra Pradesh, Orissa and Tamil Nadu on high yielding varieties. The maggots attack the leaf blades even before unfurling and the initial damage is characterised by the presence of narrow stripes of whitish area in the blade margins. The tillers become stunted. Boot leaf and spikelet damage has also been noticed. The maggots feed on spikelets and cause shrivelling. A female lays about 100, cigar-shaped eggs singly on either side of leaves during a period of three to seven days. Incubation period is two to six days and the larval period lasts for 8-17 days. Pupation takes place in between the leaf sheath and the adult emerges in five to nine days. There are 10-15 overlapping generations. It breeds on *Cynodon dactylon, Echnichloa crusgalli* and *Fimbristylis miliacea.*

Effective insecticides against the pest are sprays of endosulfan, quinalphos and fenthion at 0.5 kg a.i./ha, or application of granules of chlorpyrifos, carbofuran and fenthion at 0.75 kg a.i./ha.

Superfamily NOTHYBOIDEA

This includes the families Nothybidae, Psilidae, Periscelididae and Teratomyzidae.

Superfamily TANYPEZOIDEA

This includes the families Tanypezidae and Heteromyzidae.

Superfamily MUSCOIDEA (Calyptratae)

This includes a number of important families such as Scatophagidae, Anthomyiidae, Muscidae, Gasterophilidae, Oestridae, Calliphoridae, Tachinidae, Glossinidae, Hippoboscidae, Nycteribiidae and Streblidae.

Family Anthomyiidae

Two subfamilies are recognised in this family. The Anthomyiinae are dark coloured and possess fine erect hairs on the lower side of scutellum and more than one sternopleural bristle. They are mostly phytophagous, some are scavengers and others are parasitic. The Scatomyzinae are devoid of such erect fine hairs on the undersurface of scutellum and only one sternopleural bristle is present. They breed in cow dung.

Different species of *Atherigona* are known to infest a wide variety of cereals and are often serious pests. The rice seedling fly *Atherigona oryzae* occurs in India, Sri Lanka, Pakistan Malaysia, Indonesia and Philippines. The other species that attack rice in other countries is *A. orientalis.* In India, *Atherigona naqvii* on wheat and barley, *A. bitubeculata* on wheat, *A. simplex* on *Paspalum scrobiculatum*, *A. soccata* on sorghum and *Eleusine coracana*, *A. approximata* on *Pennisetum typhoideum*, *A. destructor* and *A. atripalpis* on *Setaria italica*, *A. miliaceae* on *Panicun miliaceum*, *A. falcata* on *Echinochloa colona* are some anthomyiid pests of importance.

1. THE SORGHUM SHOOTFLY *Atherigona soccata*

The insect is found distributed in India and West Africa.

The maggots bore into the stem of young plants of sorghum generally up to four weeks from germination and cause dead hearts. Maximum infestation is noticed in the third and fourth weeks from sowing. It is one of the most important pests of sorghum and in cases of severe attack almost all the young plants succumb to the attack necessitating re-sowing of crop. The tillers produced from affected plants are also attacked in turn by the pest. The late sown sorghum is damaged to a greater extent than the early sown crop. The incidence is generally severe on sorghum sown between second fortnight of October and the first fortnight of February.

The fly lays single whitish cigar-shaped eggs on the ventral surface of mostly the third and fourth leaves. A. single fly lays about 40 eggs. The incubation period is two to three days. The maggots migrate to the dorsal surface of the leaf, enter the space between the leaf sheath and axis and make a clean cut at the base of the leaf. The central succulent core begins to decay, and the maggots feed on the rotting matter. They pupate inside the stem itself and the adults emerge in about seven days. The maggots are parasitised by the eulophids, *Tetrastichus nyemitawas* and *Aprostocetus* sp. and the chalcid *Callitula* sp.

It has been shown that varieties which have irregular shaped silica units well formed from the fourth leaf onwards exhibit tolerance to the pest incidence and in highly susceptible varieties the silica units are formed from the sixth leaf onwards.

Control: As the insect affects very young plants, use of a higher seed rate and removal of affected and extra plants at the time thinning, four weeks after sowing are usually followed. However, in highly susceptible varieties this may prove impracticable. Seed furrow application of phorate 10 per cent granule or carbofuran 3 per cent granule at 1.0 to 1.5 kg active ingredient/ha affords appreciable protection.

2. THE WHEAT SHOOTFLY *Atherigona naqvii Steyskal*

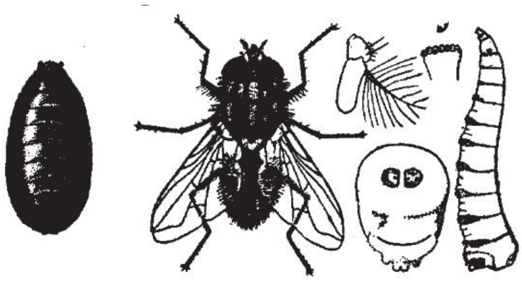
This is a serious pest of wheat and barley in Rajasthan. Infestation starts from the last week of December and continues up to March and the peak infestation is during mid January to mid March. The female lays 15–20 eggs in three to four days in the early morning hours on the base of the stems and undersurface of lower leaf blades in two or three rows, each row having three or four eggs. The egg is dirty white, cylindrical, 1.54 mm long, with dull parallel linings which run longitudinally from one end to other. The incubation period is two to three days. There are three larval instars. The newly hatched larva moves towards the leaf sheath and then between the leaf sheath and axis of the stem, and enters the stem by puncturing it from the lateral side. It cuts the growing point resulting in 'dead heart'. The larval period is seven to eight days and the full grown maggot is yellow, 5.5 mm long, the cephalic segment bearing a pair of antennae and the short and stout oral hooks. Pupation takes place at the base of stem, rarely in soil. The pupa is deep brown and measures 4.3–4.9 mm long. The adult emerges in seven to eight days. The adult is dirty grey, 4.8–5.2 mm long. The longevity of adult is six to eight days.

Family Muscidae

Small to medium sized Diptera with fleshy proboscis. Oral vibrissae are present and the adults are characterised by bristles on the mesonotum. Apical cells of wings are not narrowed distally. Larvae are typical maggots with pseudopodia, metapneustic and hemispherical stigmata.

Muscids are the houseflies (Fig. 64.7), and are agents in the transmission of diseases and a source of nuisance to man. The adults act as vectors, carrying bacteria from infected to non-infected persons.

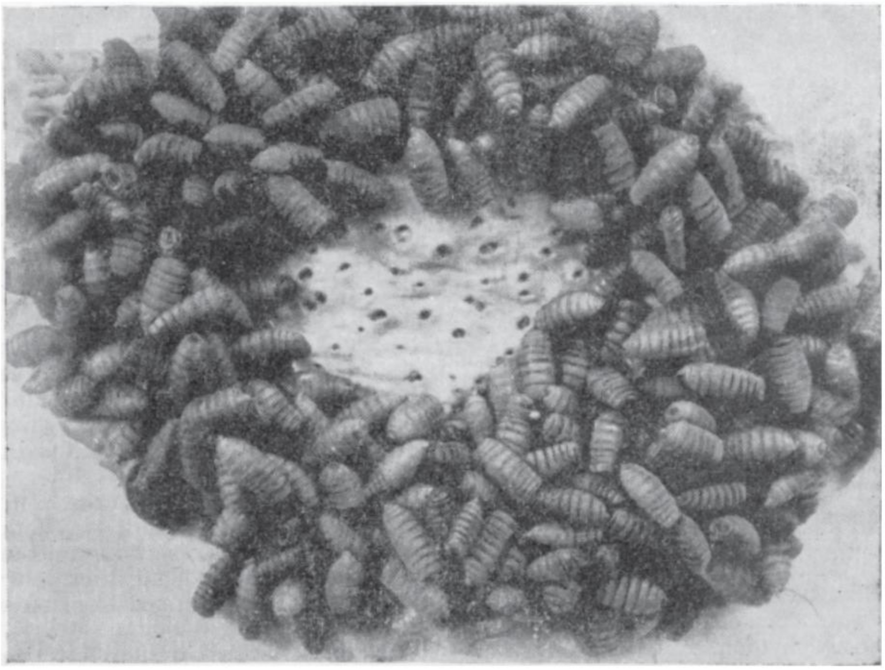
Musca nebula and *M. domestica* are common species.



▲ **Fig. 64.7** *Housefly, adult (centre), larva (right), pupa (left)(courtesy: USDA, Washington)*

Family Gasterophilidae (botflies)

These are medium sized, stout flies with bare arista and often spotted wings. The larvae live in the alimentary canal of horse, mule, ass, rabbit, rhinoceros, elephant, rarely dog and man. The horse botflies are well known. *Gasterophilus intestinalis* (Fig. 64.8) is the botfly of horse, ass and mule. It lays stalked eggs glued to the hairs on forelegs and other parts of body of the horse. The first instar larvae are ingested when the animal licks and the larvae attach themselves to the stomach wall by means of a pair of hooks.



▲ **Fig. 64.8** *Horse bots—portion of horse's stomach with bots and lesions caused by them (courtesy: USDA, Washington)*

When fully grown, the larvae detach themselves and get voided through the anus. They pupate in the ground. Occasionally *Gasterophilus* parasitises man, producing a creeping skin myiasis. However, the larvae do not live beyond the first larval stage in human host. The throat botfly *G. nasalis* oviposits beneath the jaws and shoulders and the larvae are found in pharynx, stomach and duodenum. The nose-botfly G. *haemorrhoidalis* oviposits on the hairs around the lips and the larvae are found in rectum. In Indian elephants, two species *Cobboldia elephantis* and *Platycobboldia loxodontis* are found.

Family Oestridae (warble or botflies)

Oestridae are large, stout-bodied, hairy, bee-like flies, the larvae of which are parasitic in various animals such as cattle, sheep, goats, deer, reindeer, camel and kangaroo. The flies have a large head with small eyes and facial grooves for antennae and atrophied mouthparts. In Australia, *Tracheomyia macropi* is found in the trachea of kangaroo. The most injurious species are the sheep botfly *Oestrus ovis,* the ox warble flies *Hypoderma bovis* and *H. lineatum* and the camel botfly *Cephalopsis titillator.*

1. THE SHEEP BOTFLY *Oestrus ovis*

The fly is viviparous and deposits the larvae directly into the nostrils of sheep which feed on the secretion in the frontal sinuses. This sometimes causes discharges from nose and shaking of the head and may even result in death of the animal.

Control: In logs of wood bored with sufficiently large-sized holes and edges periodically smeared with a repellent like pine tar, lumps of salt are put and the animals are allowed to lick the salt. The repellent on nose repels the fly and the use of salt licks prevents infestation. The maggots are killed *in situ* by injecting 2 ml of equal parts of carbon disulphide and liquid paraffin or 2 ml of equal parts of tetrachlorethylene and liquid paraffin or 5 ml of 25 % of tetrachlorethylene emulsion.

2. THE OX WARBLE FLY *Hypoderma lineatum*

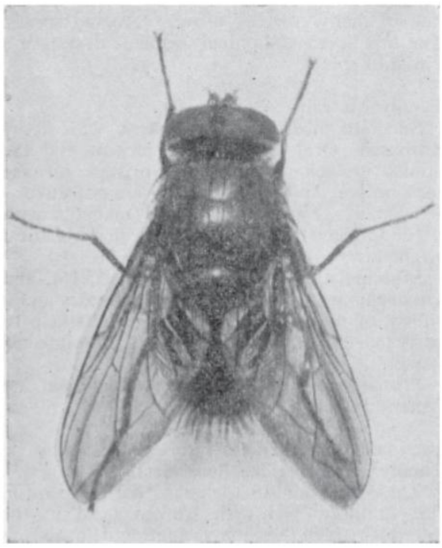
The fly oviposits on the legs close to the hooves and occasionally on back, belly and other parts of the body of cattle. A female lays about 800 eggs and the eggs are glued to hairs in small batches. The incubation period is about three days. The maggots penetrate into the skin, then burrow into the tissue, and in due course reach the mucous membrane of the oesophagus. They appear on the back in the form of warble lumps within about seven months. The maggots breathe atmospheric air through minute holes drilled by them in the lump and when fully grown they come out through these holes, drop to the ground and pupate. The pupal stage lasts for about three weeks.

As the hides of such infested cattle may have as many as 300 holes, they are rejected by leather industry. In India the incidence of the ox warble fly has been reported from Punjab, parts of Uttar Pradesh and Rajasthan. The leather industry has suffered losses running into several crores of rupees which has been attributed to the infestation of about 50–90% of the cattle population by the fly. Goats in Punjab and in some parts of Uttar Pradesh are attacked by the warble-fly *Hypoderma crossii.*

Control: The hairs close to the hooves are singed during the monsoon months and this aids in the removal of eggs. Larvicidal dressings on the warble tumours may be applied four times at monthly intervals commencing from October. The larvicidal dressing consists of the liquid obtained by straining a mixture of 1.8 kg of tobacco powder and 0.5 kg of lime soaked and frequently stirred in water for 48 hours. This is applied on the warble holes. A derris wash consisting of 0.5 kg derris powder, 113 g of soft soap and 4.5 litres of water may also be used.

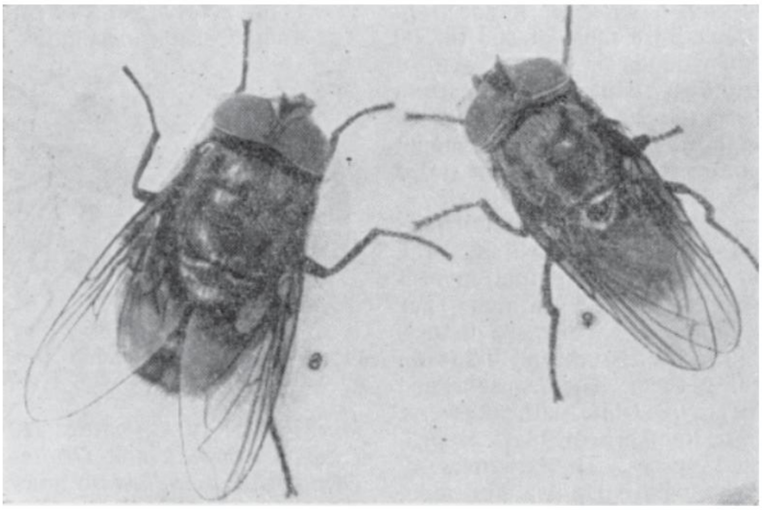
Family Calliphoridae (blowflies) (Fig. 64.9)

Blue bottles or green bottles or blowflies are large or medium sized flies of metallic shades of green or blue-green. Majority of them breed on carrion and some are serious pests causing myiasis in animals and man. The larvae are 12-segmented and three straight slits are present on each of the spiracles. Several species are pests of sheep and the important genera are *Calliphora, Lucilia* (Fig. 64.9) and *Chrysomyia.* The 'Screw-worm fly' *Cochlomyia hominivorax* (Fig. 64.10) is well known.



▲ Fig. 64.9 *Green bottle fly (Lucilia) (courtesy: USDA, Washington)*

The Sarcophaginae or fleshflies are moderately sized of grey and black colour; their arista bare distally and plumose basally. The females lay eggs in putrefying meat. Some species are larviparous often laying larvae on some putrefied material. Some lay them inside the nostrils and these are the myiasis producing flies. Sarcophagid larvae are 12-segmented and *Sarpophage ruficornis* produces myiasis in India.



▲ **Fig. 64.10** *Screw worm fly Cochliomyia hominivorax* (courtesy: US DA, Washington)

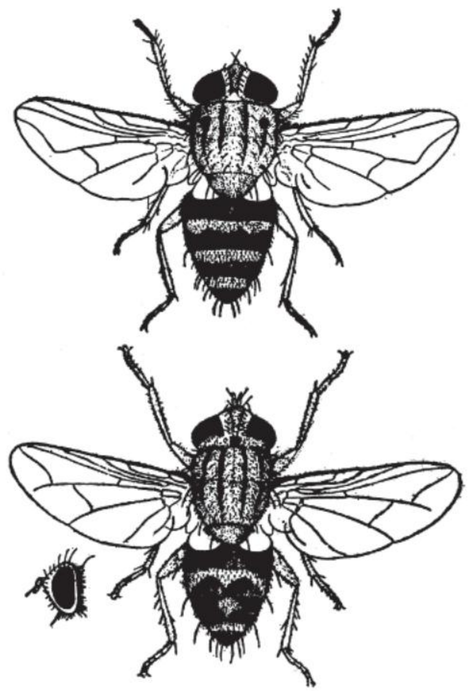
Calliphora erythrocephala, the large, bluish species, a hill form, is the common European blue bottle. It breeds in meat and dead bodies and has also been known to cause fatal gastric myiasis. Eggs of *Calliphora* hatch in 24 hours, and larval and pupal stages are known to be completed in ten days. *C. pattoni* also recorded from the hills, is larviparous. *Lucilia cuprina*, a typically African species known all over India, is the well-known blowfly of sheep in Australia. It lays eggs in a mass of 400 to 500 in fresh meat or in wounds or sores on skin of cattle. The larvae are dirty white while the puparium is light brown in colour. The bronzy-green *Lucilia sericata* is well known in India as sheep maggot fly. It usually lays more than 1,000 eggs in soiled wool of sheep.

Chrysomyia bezziana is the commonest myiasis producing fly in India. It causes rhinal, oral, aural, ocular, cutaneous and vaginal myiasis in cattle, horses, elephants and even man. They lay over 500 eggs directly on diseased tissues, the larvae penetrating the tissues and living on the fluid surrounding them. The larvae called "screw worms" are greyish white, with transverse rows of short, stout, light brown, black tipped, posteriorly directed spines. The spiracles of anterior side of the body have papillae. The puparium also has transverse rows of short spines. Life cycle is completed in about two weeks.

The meat-infesting *C. megacephala* is also common throughout India. They are attracted by the fermenting juices of decomposing flesh. The larvae cause myiasis in animals. They oviposit in decomposing animal matter and lay over 400 to 600 eggs. The prothorax of the larvae have a belt of many rows of brown, recurved spines. The first seven abdominal segments also have a girdle of spines.

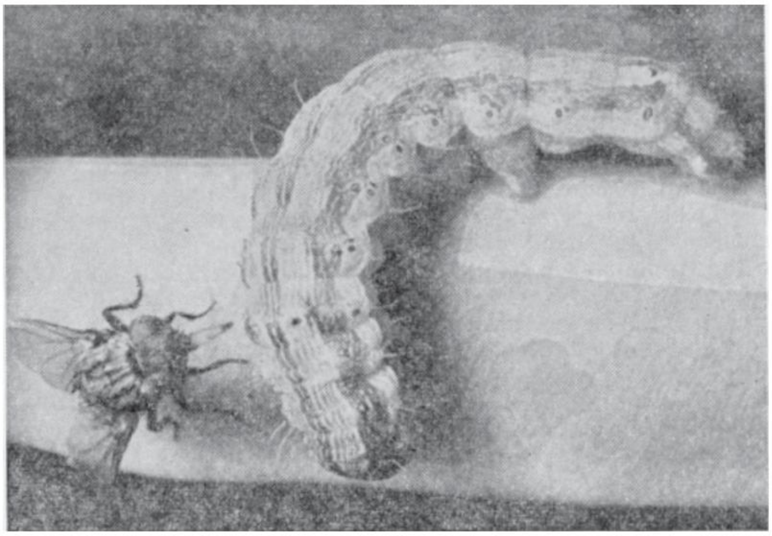
Family Tachinidae (tachinid flies)

Tachinidae are small or medium sized, black or brown flies characterised by well-developed hypopleural and pteropleural bristles and prominent post-scutellum. They have both small and long bristles covering the abdomen (Figs 64.11). They are endoparasites of larvae or pupae of Lepidoptera, Coleoptera, Hymenoptera, Diptera, Hemiptera, Dermaptera, and Orthoptera. These insects are of considerable biological interest and importance. In many species the eggs are cemented to the skin of their host and the larvae that hatch out from the eggs penetrate the body of the host and feed on the internal contents, as in *Winthemia, Eutachina*, etc. In *Exorista, Voria, Plagia*, etc., which are virtually viviparous, the larvae are deposited on their hosts. Numerous species lay their eggs on plants and the eggs are ingested by the host larvae while feeding and the eggs develop within the bodies of the hosts as in *Sturmia, Zenillia, Gonia*, etc. Some tachinids such as *Echinomyia, Dexia, Prosena,* etc. oviposit on the leaves and the flattened newly emerged larvae (planidia) get themselves attached to suitable hosts when they pass by. In a few cases the eggs or larvae of hosts are pierced with a spine-like apparatus and eggs laid internally (*Ocyptera, Alophora,* etc.). Pupation takes place within the last larval skin inside the dead host itself or in the soil.



▲**Fig. 64.11** *Tachinid flies—Strumia bimaculata (top) and Tachina fallax (Bottom)*

Some common tachinid parsitoids in India are: *Actia monticola* on larva of *Spodoptera litura, Exorista civiloides* on larva of *Amsacta albistriga, Gonia rufitibia* on pupa of *Euxoa* *segetum*, *Drino imberbis* and *Eucletoria* sp. on larva of *Helicoverpa armigera* (Fig. 64.12 and 64.13) and *Sturmiopsis inferens* on larvae of *Scirpophaga incertulas*, *Chilo partellus* and *Sesamia inferens.*



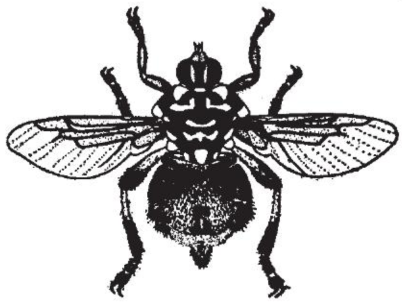
▲ **Fig. 64.12** *Drino imberbis parasitising a larva of Helicoverpa armigera (courtesy: V.P. Rao)*

▲ **Fig. 64.13** *Full grown maggots of Eucletoria sp. emerging out of Helicoverpa armigera caterpillar (ibid)*

Family Hippoboscidae (louseflies)

These are minute to small, dark brownish, flat, leathery flies with sunken head in the anterior part of the thorax, a retractile proboscis with a sheath formed of palpi, short and stout legs, wings may be either present or absent. They are commonly found on cattle and dogs. These insects are ectoparasites of birds and mammals.

The Indian species include *Hippobosca maculata* (Fig. 64.14) on cattle; *H. capensis* on dog; *Lynchia exornata* and *Ornithomyia* on pigeon; *Ornithophila metallica* on house sparrow (*Passer domesticus*), seven sisters (*Turdoides terricolor*), and crow (*Corvus splendens*), *Pseudolynchia* sp. on ringed dove (*Streptopelia senegalensis*), and *Lynchia* sp. on seven sisters.



▲ **Fig. 64.14** *Hippobosca maculata (T.B. Fletcher, 1914)*

Family Nycteribiidae (bat-ticks)

These insects are apterous and are characterised by having the head folded back in a groove on the dorsal aspect of the thorax. The eyes and ocelli are either vestigial or wanting. The two-segmented antennae have bristles on tubercles. The legs are long with big claws. They are ectoparasites of bats and cling to the skin or fur of bat. *Raymondia pagodarum* and *Cyclopodia hopei* are some of the Indian species.

Family Streblidae (Bat flies)

These flies differ from Nycteribiidae chiefly in not having the head folded back on the dorsum of the thorax and the palpi not sheathing the proboscis. The two-segmented antennae are located in pits. The legs have enlarged hindcoxae and simple claws; wings are often vestigial or wanting. These flies are ectoparasites of bats.

Family Cuterebridae (robust botflies)

The flies are large, robust and rather hairy. The larvae of these flies are mostly parasitic on rodents. However, the species *Dermatobia hominis* targets human beings. It oviposits on mosquitoes and when the mosquito bites human the larvae penetrate the skin and gain entry. The eggs of the botfly may also be carried to man by stable flies and other muscids.

Superfamily MICROPEZOIDEA

This includes four families viz. Micropezidae, Neriidae, Cypselosomatidae and Psudopomyzidae.

Superfamily DIOPSOIDEA

This includes the families Diopsidae and Syringogastridae.

Family Diopsidae (STALK-EYED FLIES)

Diopsidae flies are extraordinary in that they have long stalked eyes borne on a snout-like head. The subcosta is either wanting or poorly developed and R_1 ends before the middle of the wing. They are saprophagous or phytophagous. *Diopsis thoracica* and *D. tenuipes* damage rice (*Oryza sativa*) in Cameroon, Rhodesia, Nigeria and Sierra Leone.

Superfamily SCIOMYZOIDEA

The families included are Coelopidae, Dryomyzidae, Sciomyzidae, Ropalomeridae, and Sepsidae.

Superfamily ANTHOMYZOIDEA

This includes Heleomyzidae, Anthomyzidae, Asteiidae, and Sphaeroceridae.

Superfamily AGROMYZOIDEA

This includes Clusiidae, Agromyzidae, Mormotomyiidae, Odiniidae, Tethinidae, Milichiidae, Chloropidae, Conopidae, Richardiidae, Piophilidae, Tephritidae, and Otitidae.

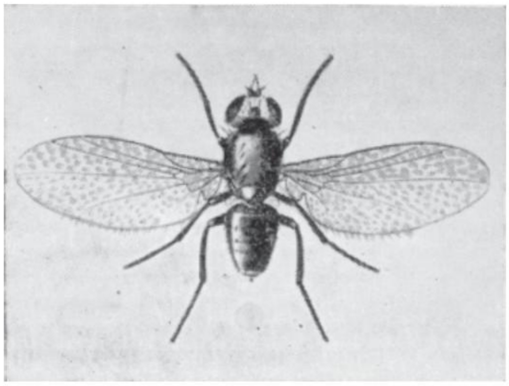
Family Agromyzidae (LEAF-MINER FLIES)

Agromyzidae are small to minute, blackish or yellowish flies, the larvae of which are usually leaf miners. The larvae of some tunnel into stems, roots and developing seeds in pods. They pupate in the larval mine or in the soil. The larvae of this family are characteristic in having sphaeroidal concretions of calcium carbonate in the malpighian tubes.

Some of the agromyzid leaf-miners found in India are *Melanagromyza beckeri* on *Launea nudicaulis* (Compositae), *M. alysicarpi* on *Alysicarpus vaginalis* (Leguminosae), *M. polyphaga* on *Thevetia neriifolia* (Apocynaceae) and *Cryptoleypis buchanani* (Asclepiadaceae), *Phytobia humeralis* on *Erigeron linifolius* and *Blumea wightiana* (Compositae), *Liriomyza brassicae* on *Brassica campestris* and *Tropeolum majus*, *Pseudonapomyza alternanthera* on *Achyranthes aspera* and *Barleria cristata* (Acanthaceae), *P. asiatica* on *Cynodon dactylon*, *Eragrostis nigra* and *Oryza sativa,* and *Chromatomyia horticola* and *Liriomyza trifolii* on a variety of plants. *Melanagromyza obtusa* and *M. phaseoli* are well known pests of pulses in India.

1. THE PEA LEAFMINER *Chromatomyia horticaola*

The pea leafminer (Fig. 64.15) is found in Europe, USA, India, USSR, Australia, Italy and New Zealand. The larvae mine into the leaves and eat through the mesophyll leaving the two epidermal layers intact.



▲ **Fig. 64.15** *Pea leaf-miner—adult*

The mated female fly punctures the leaf with its ovipositor either for feeding on the plant juice or for oviposition. The pre-oviposition period is about four days. It inserts its ovipositor into the leaf tissue and forms a triangular blotch and deposits a single egg. A fly may lay series of eggs in similar blotches close to one another. A female lays as many as 329 to 358 eggs during an oviposition period of a little less than a month. The egg is colourless and oval to elongate in shape. The incubation period is three to four days. The fully grown larva is about 3 mm long and 0.75 mm broad. The mines widen and become distinct with pellets of frass and excreta in them. It is very rare that the mines coalesce into one another. The larval period ranges from 5 to 12 days. It pupates in the larval mine and the puparium is long, oval and pale yellow in colour. The adult fly emerges in 7 to 15 days. Moderate temperature and high humidity are favourable for the development of the fly. It is generally active from January to May and passes four to five generations. The summer and autumn are passed in the pupal stage.

In India, it breeds on pea, mustard, *Brassica napus*, cauliflower, cabbage, knolkhol, turnip, radish, *Eruca sativa*, safflower, *Helichrysum bracteatum*, lentil, berseem, *Pisum arvense*, *Melilotus purviflora*, *Tephrosia purpurea*, hollyhock, *Malva sylvestris*, barley, carrot, *Solanum melongena*, potato, *Petunia phoenicea,* linseed, poppy, *Phlox drummondi*, *Viola odorata*, *Spinacea oleracea* and *Tropoeolum majus.*

Control: The larvae are parasitised by *Neochrysocharis* sp., *Solenotus* sp. (Eulophidae) and *Opius* sp. (Braconidae). Foliar spray application of phosphamidon 0.035 %, methyl demeton 0.03 %, dimethoate 0.08 % and carbaryl 0.2 % affords protection during the peak period of activity of the pest for a period of two weeks. Sowing of seeds of *Nasturtium* soaked for four hours in methyl demeton 0.5 % or phosphamidon 0.25 % affords protection to the plants for six weeks from germination.

2. THE PEA STEM-FLY *Melanagromyza phaseoli*

The insect is seen in India, Sri Lanka, New South Wales, Philippines, East Indies and China.

The maggots burrow into the stem causing withering and ultimate drying of affected portions. Often it assumes serious proportions and causes appreciable damage.

The metallic black flies mate two to six days after emergence. The pre-oviposition period is two to four days. The female inserts her ovipositor into the leaf and sometimes the stem and petiole and makes an elliptical cavity under the epidermis. The fly may feed on the liquid that oozes through the puncture or may lay the eggs in the cavities made. It is seen that 15 % of the punctures contain eggs. A female lays 14 to 64 eggs, the average being 33. The egg is elongate, oval and white and the incubation period ranges from two to four days. The maggot mines through the leaf towards the petiole and in a day or two reaches the stem. It passes through three instars and the fully grown maggot measures 0.8 by 0.2 mm. It pupates in the stem itself after making an exit hole through which it emerges. The larval and pupal periods vary respectively from 9 to 12 days and 18 to 19 days in November-December and six to seven days and five to nine days in March-April. The insect is generally active during July-April and pass through eight to nine generations. During winter it remains inactive in the pupal stage and it appears that the hot dry months are passed in the adult stage.

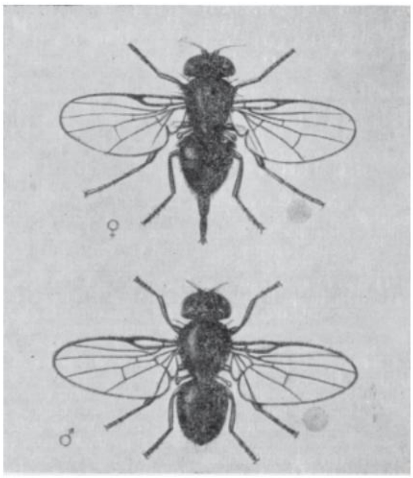
The insect attacks many pulse crops in India. It breeds on *Phaseolus mungo, P. aconitifolius Pisum sativum, P. arvense, Glycine hispida* (soybean), *Vigna catjang* (cowpea) and *Lablab niger.*

3. THE REDGRAM OR "TUR" POD FLY *Melanagromyza obtusa*

The insect (Fig. 64.16) is widely distributed throughout India. It is also found in Japan.

It is well known as one of the most serious pests of pigeon pea (*Cajanus cajan*) in India. The maggots feed on the developing seeds in pods and make them unfit for consumption. In the field up to 86 % of pods are infested resulting in damage to seeds varying from

6.0 to 63.4 %. The percentage loss in weight of pigeon pea seeds varies from 0.8 to 3.3 %. Apart from pigeon pea it also attacks lady's finger (*Abelmoschus esculentus*) and safflower (*Carthamus tinctorius*) in South India. Other hosts noticed are *Atylosia* spp., *Tephrosia* sp., *Rhynchosia rothii, R. bracteata, R. suaveolens* and *R. cana.* The maggots bore through the stem tissue of young plants and side shoots of mature plants resulting in formation of gall-like swelling, wilting and ultimate death of plants or branches. It infests pigeon pea from October to April, lady's finger from July to November and safflower during November.



▲ **Fig. 64.16** *Melanagromyza obtusa*

The metallic black flies mate a day after emergence. The female pierces the pericarp of the tender pod of pigeon pea with its ovipositor and lays a single egg. It lays about four to seven eggs in a pod and a female lays an average of 38 eggs, the maximum being 79. On lady's finger it pierces the stem or side-shoot and oviposits. The egg is white, broad and rounded posteriorly and narrowed anteriorly into a curved elongate hollow process. The incubation period is three to four days. The maggot becomes fully grown in 9 to 11 days and measures 3.5 to 4 mm long. It pupates inside the pod of pigeon pea or in a tunnel just below the epidermal layer of the stem. The adult fly emerges in eight to nine days.

Control: The maggots are parasitised by an eulophid *Euderus lividus.* Other parasitoids include *Ormyrus* sp. and *Eurytoma* sp. In Coimbatore (South India) advancing the usual sowing of pigeon pea to May instead of July has resulted in lower incidence of the pest. Dusting quinalphos 1.5 % thrice at fortnightly intervals commencing from the flowering stage affords protection against the pest on pigeon pea.

Family Conopidae (thick-headed flies)

Conopidae are medium-sized brownish flies with long antennae, a very long and slender proboscis, and slender elongate abdomen. Many resemble solitary wasps. The larvae of conopidae are parasitic, especially on adult bees, wasps, grasshoppers, etc. The flies usually chase and lay eggs on their hosts during flight.

Some species that occur in India are *Conops nubeculosus*, *C. erythrocephala*, *Physocephala bicolor*, *P. rufescens*, *P. tenella*, *Myopa nigriventris* and *M. testacea.*

Family Tephritidae [Trypetidae] (fruitflies)

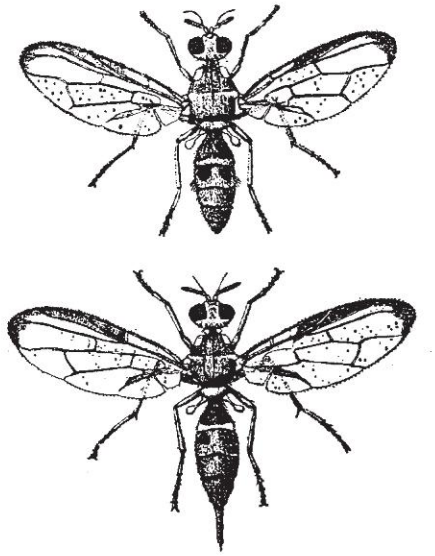
The Tephritidae are small to medium-sized insects usually with spots or bands on wings. The wing venation is characteristic in that the subcosta bends apically forward at almost a right angle and then fades out.

These insects are of considerable importance in agriculture as the larvae of most species are phytophagous. They destroy fleshy fruits of a number of economic plants and trees and some attack flower heads of Compositae. A few mine leaves or form galls on plants.

The Mediterranean fruitfly *Ceratitis capitata* on citrus and other fruit trees and the apple maggot *Rhagoletis pomonella* on apple are some notorious pests in this family. In India, *Bactrocera dorsalis, B. cucurbitae, B. ciliatus* (Fig. 64.17), *Carpomya vesuviana* and the safflower budfly *Acanthophilus helianthi* are some important pests. The exotic tephritid fly *Procecidochares utilis* causes galls on *Eupatorium adenophorum*. This tephiritid fly is seen infesting the plant from Gudalur to Coonoor on the Nilgiris.

1. THE CUCURBIT FRUITFLIES *Bactrocera cucurbitae* and *B. ciliatus* (Fig. 64.17)

Bactrocera cucurbitae is distinguished by its conical abdomen and brown markings on the wings whereas *B. ciliatus* is slightly smaller in size. These insects are known to infest the fruits of cucurbitaceous plants such as *Momordica charantia, Trichosanthes anguina*, melons, cucumbers, *Coccinia indica*, etc. *B. cucurbitae* has also been noticed to infest stem galls on *Coccinia indica* caused by the midge *Lasioptera cephalandrae*. Both the above mentioned species also occur in the stem galls on *Coccinia indica* caused by the midge *Bimba toombii*.



▲ **Fig. 64.17** *Bactrocera ciliatus, male and female*

The fly hibernates as adult during cold months and becomes active in hot weather. Breeding starts with the outbreak of rains. The adult female inserts the eggs singly or in clusters of four to ten into the flowers or ripening fruits. The eggs are shiny white, slightly curved, cylindrical in shape and narrow at one end. The incubation period is two to nine days. The maggots feed on the internal contents of fruits and make them unfit for consumption. Depending on the weather the larval period extends from three days in summer to three weeks in winter. The maggots when fully grown come out of the fruits and drop to the ground where they pupate at a depth of 1.5 to 15 cm. The pupal period is five to nine days in summer and may extend up to four weeks in cold weather. The life-cycle occupies about 12 to 34 days depending on weather. In South India about six broods of the fly *B. ciliatus* in a year have been noticed. The hymenopteran *Opius incisi* is parasitic on the insect.

Control: Collection and destruction of affected fruits is advisable. Poison baiting with fermented palm juice or protein hydrolysate is suggested. Foliar spray application of carbaryl 0.1 %, malathion 0.05 % or deltamethrin 0.0025 %, during the early hours of the morning when the flies congregate in large numbers, four times at biweekly intervals commencing from flowering, brings about appreciable reduction in pest infestation.

2. THE ORIENTAL FRUITFLY *Bactrocera dorsalis*

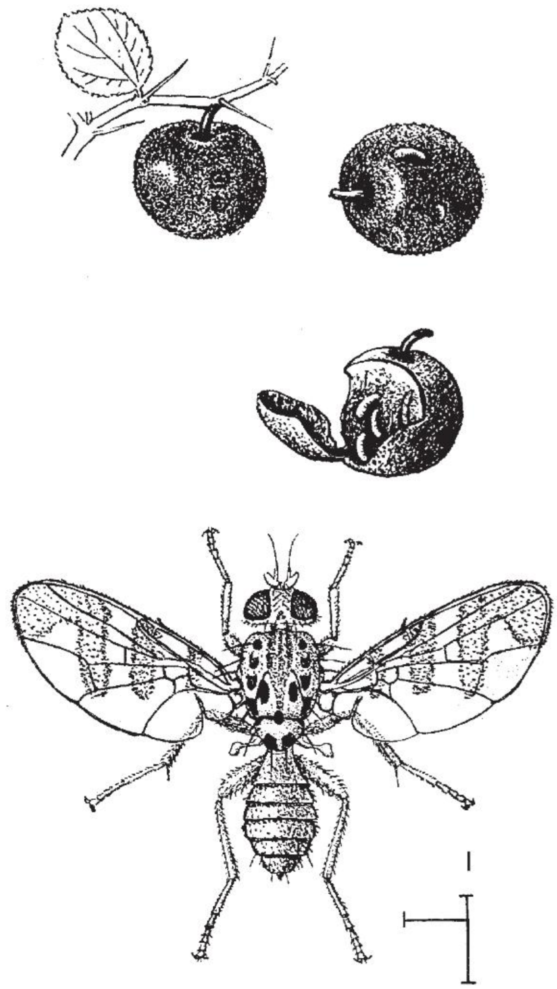
This is one of the major pests of mango in India. Apart from mango (*Mangifera indica*) it also attacks a wide variety of fruits and vegetables like *Solanum melongena, S. verbascifolium, S. trilobatum, S. aurantium, S. robustifolium, S. auriculatum, S. muricatum* and *S. torvum. Citrus* spp., etc. It attacks semi-ripe fruits of mango and citrus and sometimes causes appreciable damage to them. The insect is light brown with transparent wings. The maggots feed on the pulp of fruits and cause brown, rotten patches on the attacked fruits which fall down eventually. The maggots come out of the fruits and pupate in the soil.

Control: Spray application of deltamethrin 0.0025% thrice at 15 day interval commencing 45 days after fruit set is effective in minimising damage by fruit flies. Methyl eugenol 10 ml and malathion 20 ml in 200 ml water taken in a basin and kept at 1 basin for 20 trees is an effective bait. Baits containing 50 ml toddy and 50 g sugar/jaggery mixed with 5 ml malathion are also suggested.

3. THE BER FRUITFLY *Carpomya vesuviana* (Fig. 64.18)

The insect is prevalent in lndia, Pakistan and the Middle-East extending up to southern Europe. It is the most important pest of ber in North-West India. This is one of the major pests of ber fruits (*Zizyphus*) as nearly 80 % of fruits in the crop are rendered unfit for consumption. It is active early in spring and again in autumn, and the summer is passed in pupal stage. Its incidence is serious during February-March. The fly oviposits on semi-ripe fruits. The maggots feed on the pulp and pupate in the soil underneath the trees. The life cycle ranges from six weeks to nine months.

It is a destructive pest of ber in Haryana. The size of the fruit, its physical condition and location on the tree proved important for oviposition by the fruitfly. Oviposition preferentially occurs towards the distal or central portion of the fruit. Oviposition results into arrestation of the growth of the surrounding tissues giving the fruits rugged appearance in form of protuberances and/or depressions or both. When younger fruits are punctured the deformity produced is more conspicuous. Off season fruits of *Zizyphus mauritiana* possess more ruggedness than seasonal fruits. Crinkling of ber is not observable in fully developed fruits during spring. Ber fruits smaller than 9 mm × 4.5 mm are not punctured by the females for oviposition. With increase in their size a gradual increase in oviposition and



▲ **Fig. 64.18** *Ber Fruitly. Top—Affected fruits with maggots; Bottom—Adult fly (after T. V. R. Ayyar, 1940)* infestation occurs. In an infested crop, nearly 50% of fruits measuring 20 mm × 9 mm and above contain oviposition punctures. A maximum of 55% infested ber fruits contain a single maggot, wheras 37% contain two to three maggots. Rarely as many as seven to eight maggots can be noticed in a fruit.

Control: In Madhya Pradesh a chemical control schedule of three or four sprayings at tri-weekly interval commencing from last week of November (from first week of November in early ripening varieties), the first two with lindane 0.1 % (before ripening), the third with malathion 0.06 % (during ripening) and depending on necessity a fourth with malathion 0.06 % has been recommended. In Haryana two sprays of fenthion 0.1 % or endosulfan 0.07 % or malathion 0.04 %, the first at the stage of 80 % of the fruits being at pea-size followed by the second spray three weeks later is recommended.

▲ **Fig. 64.19** *Siphonculina funicola (T.B. Fletcher, 1914)*

Family Chloropidae

These are small, light coloured insects without the anterior orbital bristles, the bare arista and the small oral fossa. The larvae are mostly phytophagous and a few are predaceous. The fritfly *Oscinella frit* is a pest of cereals such as oats, barley and rye in temperate countries. In India and Bangladesh it infests rice causing formation of whitish hollow outgrowths of the internal leaf. In Vietnam, Japan and Korea rice is attacked by the rice stem maggot *Chlorops oryzae*. In South India, *Formosina flavipes* and *Chalcidomyia atricornis* infest the growing shoots and underground haulm of ginger, the former species also infests cardamom. The eye-fly *Siphonculina funicola* (Fig.64.19) is a nuisance to both animals and human beings as it frequents their eyes and is often responsible for transmission of various diseases like the red eye.

THE GINGER SHOOT FLY *Formosina flavipes*

It attacks young and establishing new plantations of ginger (*Zingiber officinale*) between November and June. The larvae feed on the soft tissue of the shoot and causes 'dead heart'. The peak damage occurs during March-April. The life cycle takes 49-52 days and the damage varies from 25 to 100 % of the crop. It is severe where there is inadequate shade in the initial stages. The parasitoid *Opius mudigerensis* has been reported to parasitise the crop to the extent of 75 % during May. Application of carbofuran 3 G at 20-25 kg/ha was found effective in minimising its damage.

◆ Chapter 65

Order Lepidoptera

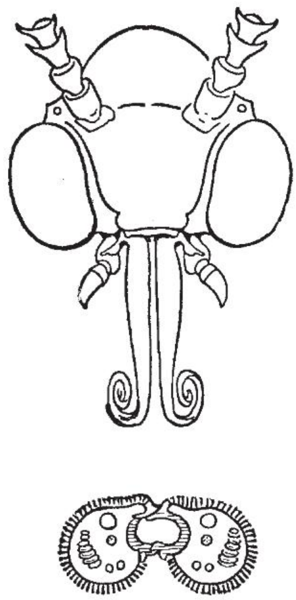
Moths and Butterflies

The moths and butterflies included in this order are soft bodied insects and vary greatly in size from minute to very large insects. They are characterised by the body, wings and appendages being generally covered densely with pigmented scales, which provide the colour patterns characteristic of the species. Lepidoptera is one of the largest of the insect orders with more than 105,000 known species. The moths and butterflies are well known to all and they are of considerable economic importance. The larvae of most species are phytophagous feeding on cultivated crops, various fabrics and stored grain or meal. Adult moths of a few species are known to suck the fruit juice and cause damage to them. On the other hand the larvae of a few moths and butterflies are predaceous on scales, mealy bugs, etc. Natural silk is obtained from the silkworm moth. Many are collected by insect collectors for their beauty and may even serve as the basis of art and design.

Adult

Head: The head of the adult is hypognathous and is relatively small. The clypeus occupies the greater portion of the head. The compound eyes are large and set well apart. The ocelli are two in number in most of the moths one on each side close to the margin of the compound eye. The ocelli may be replaced by a pair of sensory organs known as the chaetosema in some families. The antennae vary greatly in their structure and length and secondary sexual characters may be well exhibited in the pectinate and bipectinate antennae of certain male Lepidoptera.

The mouthparts (Fig. 65.1) are of sucking type having a proboscis and in a few cases they may be vestigial, in which case the adults do not feed. Exceptionally, in the family Micropterygidae they are of the chewing type. The labrum is represented as a narrow transverse band across the lower part of the face. At the base of the proboscis lateral lobes, called palpifers, are often present. The mandibles are wanting. The suctorial proboscis is formed of two greatly elongated galeae, which are held together by hooks and interlocking spines and is kept coiled in a spiral. The laciniae may be absent or its rudiments may be present. The maxillary palpi are five- or six-segmented (Tineidae) or may be reduced or wanting as in most species. However, they are two- to three-segmented in Noctuidae and single segmented in Sphingidae, Papilionidae, and most Geometridae. The labium is found on the ventral aspect of the mouth and is reduced to a small plate. The labial palpi are three-segmented, and the hypopharynx is present. The extension of the proboscis is achieved by exerting a fluid pressure by the blood.



▲ **Fig. 65.1** *Above: Head and proboscis of Hypantria cunea; Below: Cross-section of proboscis of Danais chrysippus (Snodgrass, 1935)*

Thorax: The thoracic segments are fused and the mesothorax is the largest and the most prominent. The wings are well developed and proportionately large. They are covered by overlapping scales and on the wing membrane of most cases microtrichia or aculei are present. In some a tympanal organ may be found in the metathorax at the base of the wings. Androconia (plumules) are specialised scales found in groups on the upper surface of the wings of certain lepidopterous males and may serve as outlets for odoriferous glands. The most primitive type of venation is found in the members belonging to the family Micropterygidae whose wings are closely alike. Various forms of wing coupling apparatus are also seen. Females of certain Geometridae and Psychidae and of *Orgyia* are apterous. In *Perina nuda* (Lymantriidae) the female possesses cream white wings whereas in the male they are smaller and transparent with brown scales at the base. The wings may be held in various positions at rest.

Legs: The legs are well developed with large fixed coxae. The tarsi are five-segmented ending in paired claws. In certain families of butterflies the forelegs are reduced either in the male only (Riodinidae) or in both the sexes (Nymphalidae). In the females of bagworms (Psychidae) the legs are atrophied.

Abdomen: The abdomen is ten-segmented and frequently partly fused or telescoped. In many Lepidoptera the tympanum is situated one on either side at the base of the abdomen. The cerci are wanting.

Genitalia: The male genitalia consists of a tegumen representing the ninth segment in the form of a narrow ring encircling the apex of the body and an invaginated sternal region called vinculum which in turn forms a median saccus extending into the preceding segment. Hinged to the vinculum is a pair of claspers the most prominent organs of the external genitalia. On the inner aspects of the claspers are the spine-like harpes. Towards the hind margin of the ninth tergum is a median hook-like or bifid process, known as uncus. A median ventral sclerite, known as gnathos, is present in many Lepidoptera. The uncus and gnathos are usually supposed to represent the tergum and the sternum of the tenth segment. Below the gnathos is present the aedeagus which is supported by a sclerotised juxta. The anus opens just beneath the uncus. In the female the attenuated and telescoped terminal abdominal segments form a retractile ovipositor in many forms. The insects are oviparous and holometabolous.

Egg

The eggs of Lepidoptera are variously shaped and often coloured with beautiful sculpturings. The egg may be ovoid, flattened, fusiform, spherical or hemispherical. It is provided with a tough chorion. The eggs are laid in various ways and positions, and a large number of eggs are laid by a female. They may be laid singly in an upright position on the leaves as in butterflies or in a single mass or in groups, sometimes exceeding 1,000 as in moths. Normally the eggs hatch into larvae in a week or even earlier.

Larva

The lepidopterous larva, commonly known as caterpillar, has got a well-developed head, three thoracic and ten abdominal segments. The prothoracic and the first eight abdominal segments each bear a pair of spiracles. In the head a well-developed median epicranial suture is present. Anterior to it are a pair of narrow oblique plates called adfrontals which represent the frons. The clypeus and labrum are also well-developed. There are six ocelli on either side just behind and a little above the base of the short three-segmented antennae. The mandibles are well developed and used for biting. In leaf mining larvae they may be modified for lacerating the tissue or may be wanting as in *Phyllocnistis.* The maxilla consists of the cardo, the stipes, a single maxillary lobe and two- to three-segmented palp. The labium occupies the ventral region of the head and consists of a lightly sclerotised large mentum, a pair of triangular sclerotised submentum and the prementum carrying a median process or spinneret. The labial palp consists of a cylindrical and a minute apical segment. The mouthparts are much modified in leaf miners.

Each of the thoracic segments bears a pair of legs, each leg being five-segmented with the terminal segment (tarsus) ending in a single curved claw. There are five pairs of "prolegs" on the abdominal segments from third to sixth and on 10. The first four pairs are the abdominal feet and the remaining pair is commonly known as claspers. The proleg is fleshy, retractile and more or less conical with its apex or planta rounded or flat. Locomotion is aided by the hooks or crochets provided on the planta and they can be inverted. The ways in which the crochets are arranged afford important classificatory characters. If the hooks are arranged in a complete circle surrounded by several circles of smaller ones it it said to be in multi-serial circle (Hepialidae and *Yponomeuta* sp.). If the medial and lateral parts of the circle are absent two transverse multi-serial bands are formed. If the outer circle of smaller crochets are absent it is a uniserial circle. The arrangement is uni-ordinal if the crochets of uniserial circle are of uniform length and bi-ordinal if they are of two lengths, alternating. In the Psychidae a portion of the uniserial circle may be wanting resulting in a semicircle penellipse. In nearly all the higher Lepidoptera excepting the Hesperiidae a mesoseries occurs as frequently more than half the circle is wanting. In the Geometridae prolegs are present only on segments six and ten, their caterpillars being known as "loopers" from their method of crawling. In certain caterpillars belonging to the family Noctuidae the prolegs on segments three and four are absent and the semi-looping habit is maintained throughout life. Larvae of Micropterygidae are exceptional in possessing eight pairs of prolegs. The larvae of certain leaf miners (*Phyllocnistis* and *Eriocrania*) are apodous. Simple hairs or setae, tubercles of various types and verrucae bearing tufts of setae may be found on the body of the larvae and their arrangement provides important taxonomic characters.

Repugnatorial glands, which in some cases produce extremely disagreeable odour, are situated variously in the different species of larvae. In those belonging to the family Papilionidae they are known as osmeteria, which thrust out through a slit in the first thoracic segment. A ventral defensive gland opens at the prothoracic sternum in many larvae including those of the Nymphalidae, certain Noctuidae and Notodontidae. In the Lymantriidae on the dorsum of sixth and seventh segments a pair of eversible glands is noticed. In many Lycaenidae it may be seen on the seventh segment. Protection is obtained by many larvae through the possession of urticating or irritating hairs, which cause irritation either by mechanical action or by secreting a poisonous substance. Such hairs are known to occur in those belonging to Lymantriidae, Lasiocampidae, Limacodidae and Arctiidae. The larvae may also get protection by concealment as in case bearers (Psychidae), leaf miners (*Phyllocnistis citrella*), leaf rollers (Tortricidae) and leaf webbers (*Aproaerema modicella*). Larvae of the species of *Yponomeuta* live in dense silken webs. Protective resemblance is well exhibited in the larvae of Geometridae, which closely resemble portions of their food plant. Some are brightly coloured and appear to be distasteful to birds, monkeys, etc., and thus serve as a warning colouration. In spite of such protective structural features and colouration the larvae are also likely to be infected by viruses, bacteria or fungi in many cases. Most larvae are phytophagous feeding on foliage, stem, flowers, seeds and tubers. Some are aquatic and feed on aquatic plants. A few larvae are predaceous and larvae of cloth moths feed on dried animal material.

Pupa

Pupae are decticous exarate in the most primitive families whereas in the remaining Lepidoptera they are adecticous obtect. Most species pupate in a cocoon of silk or leaves webbed together by silken threads or of chewed fragments of wood held together by hardened secretion. Some pupate in the soil in earthen cells and others in the various plant parts. Pupae of butterflies are mostly naked and protectively coloured and are supported by silken girdles. Emergence of the imago from the pupa or cocoon is accomplished in many ways such as egress through weak places in the cocoon, secretion of softening fluid, presence of special spines on the emerging insect, etc.

Certain Jurassic fossils are considered to be those of primitive moths. A few specimens are known from the Tertiary.

Four sub-orders are recognised: Zeugloptera, Monotrysia, Ditrysia and Dacnonypha.

Suborder ZEUGLOPTERA

Adults possess functional mandibles; maxilla with well-developed lacinia, larva possesses eight pairs of abdominal legs; pupa exarate type with functional mandibles.

Family Micropterygidae

These are small moths having wing expanse less than 7 mm and include the most primitive forms of all Lepidoptera. They are diurnal and the larvae feed on the pollen of flowers. A species of *Micropteryx* is known to feed on moss. The larva of *Sabatinca* feeds on liverworts. Though Comstock considered micropterygids to be terrestrial Trichoptera, Chapman and Hinton suggested an independent order—Zeugloptera.

Suborder DACNONYPHA

Adults do not possess functional mandibles; maxilla is without lacinia; bursa copulatrix opens into the common oviduct forming a long cloacal duct with a single aperture behind ninth sternite, larva is apodous.

Superfamily ERIOCRANIOIDEA

Characterised by venation of both pairs of wings alike. Female has a single genital aperture. The families recognised under this superfamily are Eriocraniidae, Neopseustidae, Mnesarchaeidae, Agathiphagidae and Lophocoronidae.

Family Eriocraniidae

The adults have a short proboscis formed of galeae, the laciniae being absent. The apodous larvae of *Eriocrania* sp. are leaf miners on birch, hazel, oak and chestnut.

Suborder MONOTRYSIA

Adults do not possess functional mandibles; maxilla is without lacinia; larva possesses not more than seven pairs of abdominal legs; female with one (rarely two) genital aperture behind ninth sternite; male without a saccus on ninth sternite; wings are nearly always aculeate.

Superfamily HEPIALOIDEA

Members of this super family have similar venation on both pairs of wings and females possess two genital apertures on ninth segment. The families recognized are Hepialidae, Prototheoridae and Palaeosetidae.

Family Hepialidae (swift moths)

They are generally medium sized moths with short antennae and vestigial mouthparts. Some are relatively gigantic. A jugate type of wing coupling apparatus is present. Tibial spurs are wanting. The moths are variously coloured, some are bright. About 300 species are known and they are well represented in Australia. They are distributed in Australia and South Africa. The larvae are wood feeders and bore into stems of plants. *Sahyadrassus malabaricus* is found in the Nilgiris boring into tea bushes.

The other families included under this superfamily are Prototheoridae, Palaeosetidae and Anomosetidae.

Superfamily NEPTICULOIDEA

These are characterised by reduced wing venation and females possessing a fleshy ovipositor and a short cloacal duct. Larvae of many species are leaf miners in India. *Nepticula hoplometalla* and *N. elachistarcha* are leaf miners, respectively, on *Butea monosperma* and *Zizyphus rugosa* This superfamily includes the following families, viz. Nepticulidae and Opostegidae.

Superfamily INCURVARIOIDEA

These are characterised by reduced wing venation in hindwing and female possessing sclerotised ovipositor and a long cloacal duct. The families included are Heliozelidae, Incurvariidae, Prodoxidae and Tischeriidae.

Family Heliozelidae

Larvae are apodous and mine into leaves of plants.

Family Incurvariidae

In females the antennae are shorter than in males. Males possess larger eyes, which are approximated dorsally. Larvae are leaf miners, a few live in cases and feed on vegetable refuse. However, an interesting biological relationship exists between the yucca moths of the family and the yucca plants. The female moths collect the pollen with their modified maxillae and deposit the pollen on the stigma of the yucca flowers and lay the eggs in the ovaries of the flowers.

The larvae feed on the developing seeds. In this way they get perpetuated. This type of association is well seen in the North American species of Yucca moth, *Tegeticula yuccasella* associated with the yucca plant, *Yucca filamentosa.* A few species of the genus *Nemotois* are known from India.

Suborder DITRYSIA

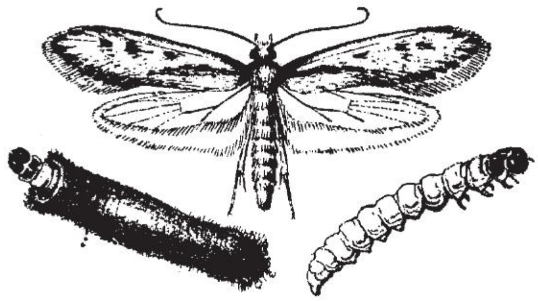
Adults do not possess functional mandibles; maxilla is without lacinia; larva possesses not more than five pairs of prolegs; pupa is obtect; female with a copulatory aperture on eighth sternite and an egg pore on ninth sternite, male with saccus on ninth sternite; wings are not aculeate; venation of fore and hindwings are not alike.

Superfamily TINEOIDAE

They are characterised by well-developed maxillary and labial palpi; the third segment of labial palpi being usually slender and pointed. Both wings possess Cu_2 and hindwings with S_c+R_1 free and M_1 and R_s separate. In some, the wings are divided into plumes.

Family Tineidae (clothes moths)

The family has world wide distribution. The moth (Fig. 65.2) has rough hairs on its head and rather long maxillary palpi. The tibiae are hairy. The larvae are destructive to clothes, furs, carpets, dried fruits, etc. The larvae generally move about enclosed in small portable cases of silk, wool, cotton, etc. The species of clothes moths that occur commonly in India are *Tinea pachyspila, T. longicornis* and *Trichophaga abruptella*. Sissoo plants are damaged by larvae of *Leucoptera sphenograpta* and *Cassia* pods by *Ereunetis seminivora. Monopis leuconeurella* bores into mango fruits in South India. *Setomorpha tineoides* attacks dried leaves of tobacco. *S. margalestriata* infests wrapper tobacco in Java and Sumatra. In India the larvae of *Demobrotis* sp. are known to attack wrapper tobacco.



▲ **Fig. 65.2** *Clothes moth, adult (above), larva (right), larva in case (left) (courtesy USDA, Washington)*

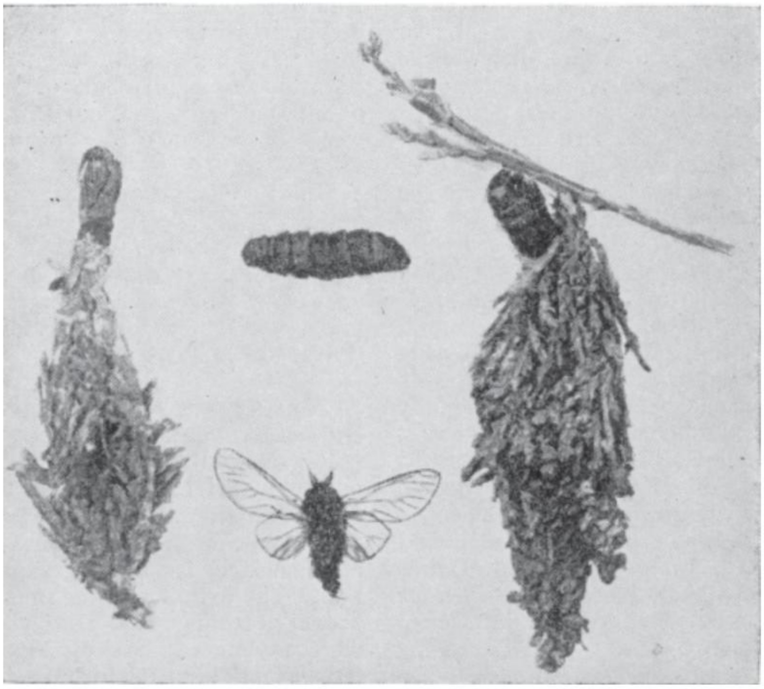
THE WRAPPER TOBACCO TINEID LARVA *Demobrotis* sp.

The larvae of the insect were first noticed to damage wrapper tobacco in West Bengal in India. The top 75 to 100 mm layer of leaves of wrapper tobacco in storage is damaged by the larvae.

The eggs are generally laid in clusters on the folded wrapper leaf of tobacco, each cluster containing 7 to 60 eggs. A female lays 6 to 140 eggs. The egg is oval, white, shiny, and measures 0.06 to 0.09 mm by 0.03 to 0.04 mm. The incubation period ranges from six to ten days. The full-grown larva is 16 to 18 mm long and pupates in a silken cocoon consisting of pieces of wrapper leaf and excreta. The pupal period ranges from 18 to 26 days. The total life cycle occupies 72 to 94 days, the average being 83 days. The longevity of moths ranges from one to four days in male and one to three days in female.

Family Psychidae (bagworm moths)

Bagworm moths (Fig. 65.3) are widely distributed. The females are apterous whereas the males are winged. Wings are thinly clothed with imperfect scales and exceptionally large frenulum. Antennae are bipectinate. Labial palpi are short. Some females are devoid of antennae, mouthparts and legs. Larvae inhabit cases, which exhibit great variety of shape and of materials used in their construction.



▲ **Fig. 65.3** *Thyridopteryx ephemeraeformis; Left: Bag with pupa protruding at tip; Middle: Top–Larva.Bottom–Adult of bagworm; Right: Bagworm hanging from twig-larva feeding on Leaf. (courtesy: USDA, Washington)*

The bagworm *Clania cramerii* is a very common species found in South India on *Acacia, Casuarina equisetifolia*, etc. The bagworm *Kophene cuprea* is a pest of banana in Kerala. *Chaliodes vitrea* and *Pteroma plagiophleps* are the other bagworms which infest tamarind leaves in India.

Family Gracillariidae

These insects are recognised by their habit of resting with the fore part of the body upraised. Larvae are apodous and mine into leaves. Adults are very small, delicate with long narrow fringed wings. The larvae of *Acrocercops syngramma* on mango, *A. coerulea* on *Lablab niger*, *Gracillaria soyella* on redgram (*Cajanus cajan*) and *G. theivora* on tea cause blotch mines.

THE CASHEW LEAF MINER *Acrocercops syngramma* M (Fig. 65.4)

The leaf miner is distributed in Andhra Pradesh, Karnataka, Kerala, Goa, Maharashtra, Orissa, Tamil Nadu and West Bengal and in other cashew countries. It is a serious pest of cashew causing 15 to 26 % damage to leaves, particularly to the tender foliage of post monsoon flushes. The larva mines in between the epidermal layers of the leaf causing leaf blisters (Fig. 65.4), which ultimately dry up and become brownish.

▲ **Fig. 65.4** *Cashew leaves damaged by leaf miner (courtesy: V. Ambethgar)*

The adult is a silvery grey moth, which lays the eggs singly on tender leaves. The freshly hatched out larva is whitish and starts mining the leaf. The full-grown larva is reddish and measures 4–6 mm long. The larval period is two weeks. The larva pupates inside the leaf mine and emerges as adult in seven to ten days. The total life cycle occupies 25-30 days. Apart from cashew it also attacks mango and *Syzigium jambolanum.* The larvae are parsitised to the extent of 59% by two eulophids *Cirrospilus* sp. and *Sympiesis* sp.

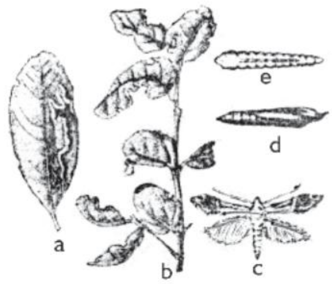
Spraying monocrotophos or fenthion 0.05% is suggested.

Family Phyllocnistidae

The larvae are apodous and mine into leaves. The citrus leaf miner *Phyllocnistis citrella* is a notorious pest of citrus trees in India. The other species include *P. toparcha* on grapevine and *P. chrysopthalma* on cinnamon.

THE CITRUS LEAF MINER *Phyllocnistis citrella* (Fig. 65.5)

This is one of the major pests of citrus in India. The apodous larvae attack only the younger and tender leaves and make serpentine mines in them. The larvae feed on the epidermal cells of the leaf leaving behind the remaining leaf tissue quite intact and the overlapping layer of leaf tissue, protecting the larva, is comprised of smooth waxy cuticle of the leaf tissue. Larvae feed in zig-zag lines and severely infested leaves get distorted in shape. In cases of severe attack occasionally the succulent shoots of orange and grape fruits are also mined. The growth of the young trees is retarded considerably and in nurseries, the plants may even die. The maximum number of mines and the longest mines are found on its preferred host, the elephant lemon (*Citrus medico*) and the least number of mines and the shortest mines are seen on lime (*Citrus aurantifolia*). Its infestation is also severe on sweet lime (*Citrus limetta*) and sweet orange (*C. sinensis*) and moderate on pumelo (*C. maxima*) and pomelo (*C. paradisi*). Older leaves of citrus are not attacked by the insect.



▲ **Fig. 65.5** *Citrus leaf miner. a. Damaged leaf, b. Damaged shoot, c. Larva, d. Pupa, e. Adult (after T. V. R. Ayyar, 1940)*

Copulation takes place mostly at night or at dawn. The eggs are laid singly mostly on the lower surface of tender leaves and occasionally on the upper surface. Rarely the eggs may be laid on the tender succulent branch. A female lays 36 to 76 eggs, the average being 48. The egg is broadly oval, slightly convex, flattened and is covered with a thin, shiny film of secretion. It measures 0.31 by 0.21 mm and the incubation period ranges from two to ten days. The larva passes through four instars. The full-grown larva is cylindrical, dull yellow in colour and measures 4.99 by 1.03 mm. The larval period ranges from 5 to 20 days depending on the season. The full-grown larva curls a small part of the edge of mined leaf over its body, spins a white cocoon and pupates inside. The pupal period varies from 6 to 22 days. The adult moth is tiny, silvery white with forewings having brown stripes and a prominent black spot near the apical margin, and white hindwings. The wings are fringed with minute hairs. The number of generations in a year may range from 9 to 13.

The larvae are parasitised by *Cirrospiloideus phyllocnistoides* (Eulophidae). The eulophid parasitoids *Cirrospilus quadristriatus* and *Tetrastichus phyllocnistoides* parasitise the larval and pupal population to the extent of 16 to 35 %.

Control: Spraying neem cake extract or neem oil emulsion or 0.05 per cent emulsion of quinalphos or monocrotophos or methyl parathion or profenofos or acephate may be useful in bringing down the infestation.

Superfamily YPONOMEUTOIDEA

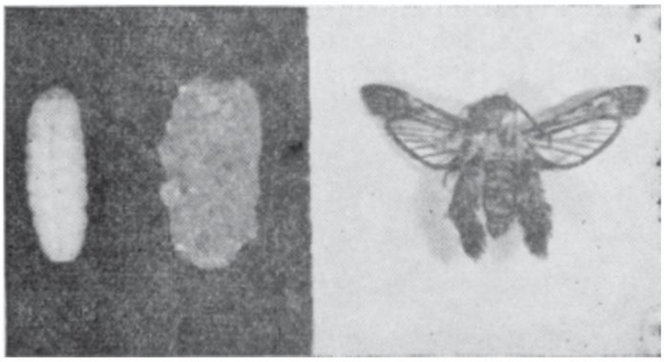
Family Sesiidae [Aegeriidae] (clear wings)

The “clear wings” are often brightly coloured with mostly scaleless, transparent wings and in appearance sometimes resemble ichneumons, wasps, bees, etc. The larvae bore into the rootstocks of plants, wood of trees, vines, etc. They may either pupate in the larval gallery or in the soil in an earthen cocoon.

The European and American currant borers *Sesia tipuliformis* and the American peach tree borer *Aegeria exitiosa* are economically important pests in these continents.

▲ **Fig. 65.6** *Gall on snake gourd vine caused by Melittia eurytion (after B.V. David and T.R. Subramaniam, 1962. Madras agric J., 49: 192–193.)*

In India this family is poorly represented. In South India the sessid *Melittia eurytion* (Fig. 65.6, Fig. 65.7) damages snakegourd vines. The larvae bore into the vines and produce elongated galls of 50 to 75 cm long and 1.2 to 1.8 cm thick. In a gall only one larva is seen. Larva pupates in the soil in an earthen cocoon.



▲ **Fig. 65.7** *Melittia eurytion larva, cocoon and adult (ibid)*

Family Yponomeutidae

The moths are usually small and brightly coloured. The larvae of *Atteva fabriciella* live in silken webs on the lower surface leaves of the tree *Ailanthus triphysa* and feed on them in the forests.

THE AILANTHUS SHOOT WEBBER, *Atteva fabriciella* Swed

This species is distributed all over India, Myanmar, Fiji, Java, Malaysia. The larvae feed on the tender leaves and other soft tissues of the terminal portion of *Ailanthus triphysa.* Larvae web around the tender leaves and feed from within. Older leaves are not usually preferred. The number of larvae at a time in a web may vary from 6-10. Often more than a single branch in a plant is attacked in addition to the terminal bud. When the tender leaves are fully eaten up, larvae may also bore into the soft tissues of the terminal portion and cause partial or complete damage to the terminal buds resulting in the formation of epicornic branches. In mature trees, larvae also cause damage to the inflorescence and tender fruits, thereby affecting seed production. Poor growth performance of *A. triphysa* in forest plantations in Kerala is attributed to infestation by the shoot webber *A. fabriciella.* Growth measurements (height and girth at breast height) for two years showed that protecting the plants against *A. fabriciella* can result in increased growth.

Host plants. Quasia indica (Fam: Simaroubaceae - same family to which *Ailanthus* belongs)

Life history: Eggs are laid singly or in groups on young buds and tender leaves. Normally the small, pale green eggs hatch out in two to three days. Larval period extends for 13-28 days with five, and rarely six larval instars. Mature larva constructs a loose cocoon and pupates. Pupa is slender, orange brown to pale yellow brown in colour. Pupal period usually ranges from 4-14 days.

Natural enemies: *Brachymeria hime atteva* (Chalcididae) parasitises the pupa, and *Bessa remota* and *Carcelia* sp. (Tachinidae) and the nematodes *Mermis* sp. and *Hexamermis* sp. (Mermithidae) are larval parasites. *Parena nigrolineata* (Carbidae), *Crebator unbana* and *Hestiasula bruminana* (Mantidae), and *Panthous bimaculatus* (Reduviidae) are predaceous on larvae. The pathogenic fungi are *Beauvaria bassiana, Paecilomyces farinosus* and *Aspergillus flavus*

Control Spraying 0.05 per cent monocrotophos or quinalphos affords control in nurseries. In plantations, insecticide application is not generally recommended. The scope of making use of some of the effective biological control agents is worth studying.

Family Heliodinidae

Small moths possessing narrow, lanceolate, fringed hindwings. The hindlegs are elevated above the wings at rest. Represented by a few members only. Some are known to mine leaves. Larvae of *Stathmopoda theoris* occur on sorghum ears in Coimbatore. Some species of *Stathmopoda* are predaceous on coccids.

Family Glyphipterygidae

Small moths, the larvae of which feed on leaves. The larvae of *Phycodes radiata* and *P. minor* web and feed on leaves of *Ficus* sp. in South India.

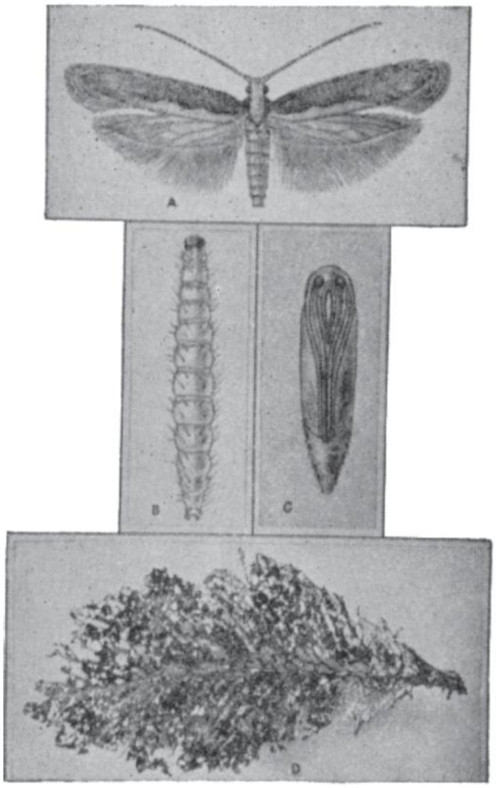
Family Plutellidae

Moths possess short porrect maxillary palpi. Larvae remain in thin silken web and feed on leaves or mine into leaves or stems. The diamond back moth *Plutella xylostella* is a destructive pest on cruciferous crops in India.

THE DIAMOND BACK MOTH *Plutella xylostella*

The insect (Fig. 65.8) has a world-wide distribution on cruciferous plants. The larvae cause serious damage to crops like cabbage, cauliflower, etc. They remain on the lower surface of leaves and drill many small holes in them, giving a shot hole effect all over the leaves. The larvae that hatch out from the eggs feed by scraping the leaf tissue and as they grow bite holes in them. A heavy infestation causes retardation in the growth of cabbage and cauliflower plants. A severe infestation results in formation of under-sized flowers in cauliflower and in cabbage head formation does not take place. On the hills the infestation is more during April to August on cruciferous vegetable crops and low during November to March.

The moth is small, greyish brown and has pale white narrow wings with yellow inner margin. When the wings are folded on its body at rest, a diamond shaped median dorsal patch is seen and hence the name "diamond back moth." The female lays minute yellowish white eggs singly on the undersurface of leaves along the veins. The moth lays more eggs on plants that contain isothiocyanates. A female lays as many as 57 eggs. The full-grown larva is light green, attenuated at both ends with minute short hairs on the body. It pupates on the undersurface of the leaf itself in a loose meshed silken cocoon. The total life cycle occupies 24 to 35 days, the egg, larval and pupal periods respectively being three to six, 14 to 21 and 7 to 11 days. Normally 8 to 12 generations are noticed in a year. The insect infests cabbage, cauliflower, kholkhol and mustard.



▲ **Fig. 65.8** *Plutella xylostella— A. adult, B. larva, C. pupa and D. damage to mustard leaf (courtesy USDA, Washington)*

The natural enemies of the insect include the larval parasites *Voria ruralis*, *Itoplectis* sp., *Diadegma fenestralis*, *D. varuna*, *Diadromus collares*, *Apanteles ruficrus*, *Cotesia* sp. (*glomerata* group), *C. plutellae*, *Tetrastichus sokolowskii*, *Chelonus versatilis*, *Brachymeria* sp., *Hockeria testaceitarsis* and *Euchalcidia* sp. The pupae are parasitised by *Brachymeria excarinata*, *B. plutellophaga* and *Horogenus* sp.

Control: Spray application of cypermethrin at 30 g a.i./ha or fenvalerate at 50 g a.i./ha or deltamethrin at 10 g a.i./ha or cartap hydrochloride at 175 g a.i./ha or novaluron 10% EC at 75 g a.i./ha once at primordial initiation (22 days after planting) followed by either two applications at 10 days interval or three applications at 7 days interval is suggested. Mustard sown as a trap crop twice i.e. 12 days preceding planting cabbage and again 40 days later minimises infestation by DBM, cabbage borer (*Hellula undalis*) and leaf webber (*Crocidolomia pavonana*).

Superfamily GELECHIOIDEA

This includes families such as Coleophoridae, Elachistidae, Scythridae, Stathmopodidae, Oecophoridae, Ethmidae, Cosmopterygidae, Cryptophasidae, Xyloryctidae, Gelechiidae and Stenomidae.

Family Gelechiidae

This family consists of a large number of small to minute moths, which are mostly cryptically coloured. The forewings are trapezoidal and narrower than hindwings. Feeding habits of larvae vary considerably and they are often destructive to crops. The groundnut leaf miner *Aproaerema modicella* often causes serious damage to groundnut crop. The larvae of potato tuber moth *Phthorimaea operculella* mine the leaves and burrow into the tubers of potato in the field and in store. Similarly the notorious Angoumois grain moth is a serious pest of stored grains like paddy, sorghum, maize, wheat, etc. and sometimes infests sorghum and paddy in the field itself. Some cause galls on stems of plants such as *Gnorimoschema heliopa* on tobacco and *Dactylethra candida* on *Tephrosia purpurea*. The pink bollworm, *Platyedra gossypiella*, is a serious pest, which feeds within the seeds of cotton and sometimes causes resetting of flowers. The larvae of *Anarsia* sp. bore into the flower buds of *Achras zapota* and affect fruit setting considerably. In Peradeniya, Sri Lanka larva of *Epithectis studiosa* was found feeding on dried plants in the herbarium.

The larva of *Holcocera pulverea* is predaceous on lac insect in India. It also feeds on the pupa by cutting through the cocoon of the neuropteran *Chrysopa madestes*, a predator on lac insect.

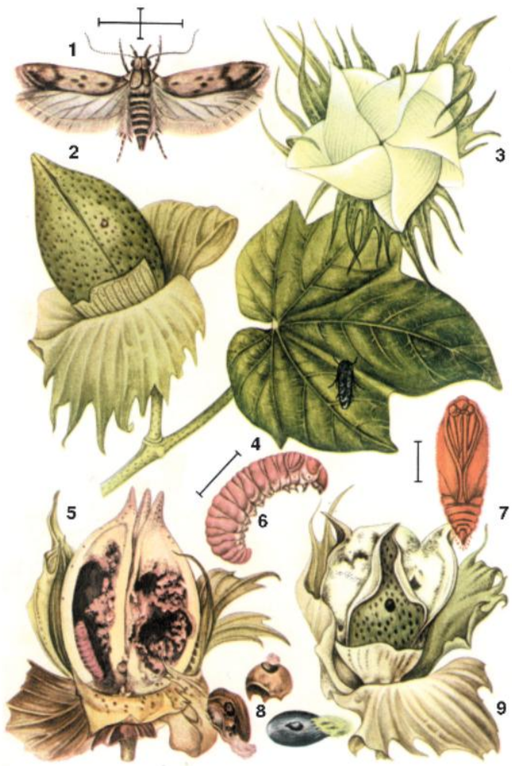
1. THE PINK BOLLWORM *Pectinophora gossypiella* (Fig. 65.9)

The pest is found all over the world where cotton is grown.

The pink larva inflicts serious damage to cotton crop in many ways: The seeds are destroyed. The development of lint is retarded and lint weakened. Infestation causes premature opening of the boll leading to invasion of saprophytic fungi and others, stain the lint both in the gin and in the boll. Infestation lowers germination power of unattacked seeds in an attacked boll. Infestation of flower buds causes shedding of the buds. When the flower is infested, a typical rosette-shaped bloom harbouring the larva can be seen. The infestation in the crop may reach up to 85 % in cases of severe attack.

The adult moth is small and dark brown in colour. Mating takes place at night soon after emergence and the moth lays eggs from the third day onwards. The female on an average lays 125 eggs, the maximum being 456. The flat striated eggs are laid on the bolls or thrust between the bracts and the side of boll and sometimes on buds and flowers. The incubation period of the eggs ranges from 4 to 25 days.

The larva bores into the boll mostly from the top and the boll closes up and nothing can be seen from outside. The larva immediately starts feeding on a seed and then moves to another seed. Often it cuts a hole through the septum and invades the adjacent lock. When attacked, buds are shed prematurely. Rosette shaped bloom indicates pink bollworm attack and such a flower invariably harbours the larva inside. The full-grown larva is pink with a dark brown head and prothoracic shield and measures 15 mm long. Larval period occupies 25 to 35 days. The larva pupates among the lint, inside the seed, in double seeds, in the bracts at the base of the boll or in cracks in the soil. The adult moth emerges in about 6 to 20 days depending on the season. In North India short-cycle larvae and long-cycle larvae are noticed. In Punjab most of the damage is caused from August to November and in winter the larvae hibernate in double seeds and emerge as moths next summer. In South India no such hibernation in any of its stage has been noticed. In North India four to five generations are recognised. The pink bollworm infests cotton, *Hibiscus cannabinus*, *H. rugosus*, *H. panduraeformis*, *Abutilon indicum*, *Althaea rosea*, *Thespesia populnea* and *Abelmoschus esculentus* in India.



▲ **Fig. 65.9** *Pectinophora gossypiella. 1. Adult; 2. Boll showing hole through which larva comes out; 3. 'Rosette' bloom; 4. Adult on leaf; 5. Attacked boll and damaged seeds; 6. Larva; 7. Pupa; 8. Damaged seeds; 9. Open boll showing hole through which larva emerges. (Bayer AG, 1968)*

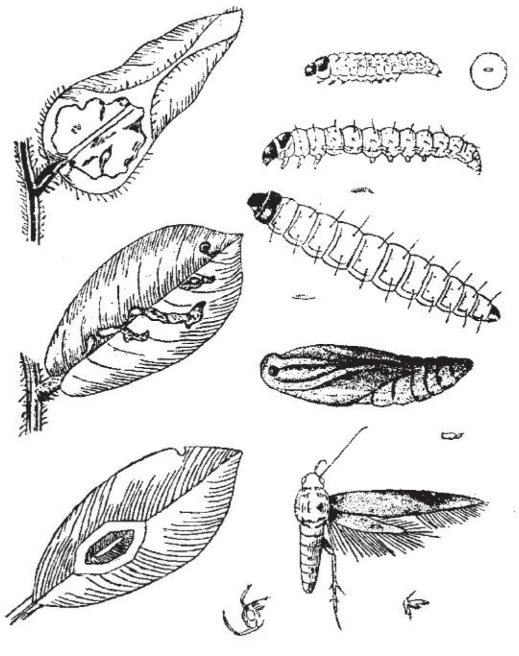
The eggs of pink bollworm are preyed upon by an anthocorid bug *Orius tantilus*. Larvae are parasitised by *Bracon lefroyi, B. kitchneri, B. greeni, B. gelechiae, Apanteles pectinophorae, Rhogas aligharensis, Petalodes gossypiella, Habrobracon hebetor* (Braconidae), *Elasmus platyedrae, E. johnstoni* (Elasmidae) and *Goniozus* sp. (Bethylidae). A mite *Pediculoides ventricosus* is also known to attack the larva.

Control: Destruction of the host plants during the off-season may be useful. Heat treatment of seeds for a few minutes to the permissible limit of 140° F before sowing kills hibernating larvae. Fumigation to kill the larvae in the seeds with methyl bromide at 1.5 kg per 100 cu.m. for 24 hours or with phosphine using aluminium phosphide or magnesium phosphide may be quite effective. Periodical spray application of carbaryl 50 WP at 1.25 kg a.i./ha, phosalone 0.7 kg a.i./ha, monocrotophos 36 SC at 0.5 kg a.i./ha, quinalphos 25 EC at 0.50-0.75 kg a.i./ha, profenofos 50 EC at 0.75-1.0 kg a.i./ha is suggested.

2. THE GROUNDNUT LEAF MINER *Aproaerema modicella* (Fig. 65. 10)

The insect is found distributed in India and Sri Lanka. It is one of the important pests of groundnut in India.

Immediately after hatching the larva mines into tender leaflets. In due course the larva folds and brings together adjacent leaflets and feeds on the leaf tissue. The leaves gradually dry up. Often, the larva causes serious destruction to groundnut and soybean. Severely infested field appears as though burnt up by fire. Extreme drought conditions seem to favour the multiplication of the pest. Rainfed crop suffers due to heavy attack by the pest than irrigated crop of groundnut. Bunch varieties are more severely infested than spreading types. The moth measures 8 to 10 mm and is grey with dark grey forewings having a white spot on the upper margin towards the apical end and light grey hindwings. The female lays shining, beautifully sculptured eggs two to three days after mating on tender leaflets singly. On an average a female lays 186 eggs, the maximum being 473. Incubation period is three or four days. The full-grown larva is about 8 mm long, smooth, uniform green with dark head and prothoracic shield. The larval period is 9 to 17 days. The pupa is enclosed in a thin silken cocoon inside the leaf folds. The adults emerge from the pupae in three to seven days. The total life cycle varies from 15 to 28 days. The adult longevity is about 36 days. In a rainfed crop the pest passes through five to six generations.



▲ **Fig. 65.10** *Groundnut leaf miner. Left: Damaged leaves; Right: Life stages of the insect (T. B. Fletcher, 1914)*

It infests *Arachis hypogaea* (groundnut), soybean (*Glycine max*), red gram (*Cajanus cajan*), *Psorolea corylifolia*, *Vigna radiata, V. umbellata, Medicago sativa, Indigofera hirsuta, Trifolium alexandrium, Teramnus labiolis, Lablab purpureus, Rhynchosia minima* and *Boreria hispida.*

The following are parasitic on the larva of the insect in India: *Avga choaspes, Bracon brevicornis*, *B. gelechiae, Habrobracon hebetor, Chelonus blackburni, C. curvimaculatus, Cotesia javensis*, *C. singaporensis*, *Phanerotoma* sp. (Braconidae), *Brachymeria minuta, B. wittei* (Chalcididae), *Sympiesis indica*, *S. dolichogaster, Stenomesius japonicus*, *Stenomesioideus ashmeadi, Euryscotolynx coimbatorensis* (Eulophidae), and *Goniozus stomopterycis* (Bethylidae) and *Plutarchia giraulti* (Eurytomidae). The larva and pupal parasitoids include *Brachymeria plutellophaga* (Chalcididae) and *Eupelmus* sp. nr. *anpingensis* (Eupelmidae). The eggs are parasitised by *Trichogramma* sp.

Control: Collection and destruction of moths by setting light traps and the moths are attracted to light from 6.30 to 10.30 p.m. and from 2.30 to 4.30 a.m. Sprays of methyl parathion or fenitrothion at 0.025 per cent, or monocrotophos or phosalone or quinalphos at 0.05 per cent or chlorpyrifos at 0.04 per cent or carbaryl 0.1 per cent is suggested for controlling the pest.

3. THE POTATO TUBER MOTH *Phthorimaea operculella*

This is cosmopolitan in distribution and is a notorious pest of potato. The insect got introduced into India (in Mumbai) from Italy about 60 years ago.

The insect occasionally infests potato crop in the field but is particularly destructive to the stored crop. In the field, the larva mines into leaves or bores into petioles, terminal shoots and developing underground tubers during November to March and attacks the tubers in storage from April to November. The infestation in stored tubers may range from 30 to 70%.

The female lays eggs during dusk. It lays about 100 to 150 eggs in or around the eyes or cracks or on the skin of exposed tubers. In the field the eggs are laid singly on the undersurface of leaves of potato. The incubation period is three to six days. The larva becomes full-grown in 5 to 16 days and is yellowish with a brown head. It pupates in a silken cocoon. In the field cocoons are found among dried leaves, clods of earth, and other trash on the ground. In storage they are seen on the seams of storage bags and in the cracks on walls and floors. The adult moth emerges in about a week. There are eight to nine generations during a storage season. The insect has been reported to hibernate as larva or pupa in some colder parts of the country. The insect multiplies rapidly under conditions of low rainfall and high temperatures.

Apart from potato (*Solanum tuberosum*) it infests tobacco, tomato, brinjal and a few other solanaceous plants.

Digging up of the mature crop minimises infestation. The tubers must be removed from the field immediately and should not be allowed to remain overnight in the field as moths may lay eggs on them. Infestation in stored potatoes, intended for consumption, can be controlled by fumigation with methyl bromide at 4 to 8 kg per 100 cu.m for 3 hours or CS_2 at 2 to 4 kg per 100 cu.m for ½ to 2 days at temperatures not exceeding 30°C. CS_2 induces sprouting in tubers and hence is not advisable. Tubers for use as seeds can be protected by dusting the bags with carbaryl 10 per cent dust or spraying with deltamethrin 2.5% WP at 1.2 g/litre water to cover 30 sq. m. area. Covering of tubers with 2.5 cm layer of sand prevents infestation. In the field periodical spraying with phosalone 0.06 per cent commencing three weeks after sprouting may be effective.

4. THE ANGOUMOIS GRAIN MOTH *Sitotroga cerealella*

The insect is cosmopolitan in distribution and is known to be one of the serious pests of stored grains. The insect is known to have been injurious to wheat since 1736 in the province of Angoumois, France, and hence the name Angoumois grain moth.

The larvae are destructive to paddy, sorghum and finger millet (*Eleusine coracana*) as they infest ripening grains in the field and also the grains in storage. The adults can be seen flying about in large numbers in storage bins or on bags and on the surface of grains.

The moth is buff coloured with pointed hind-wings possessing heavy fringe of hairs. The female moth lays the minute eggs singly or in groups on the grains. The larvae that hatch out from the eggs burrow into kernels and feed on the starchy part. The larvae and pupae are found entirely inside the seeds. It is a serious pest of unhusked paddy in India.

Family Cosmopterygidae

They are minute narrow-winged moths. The antennae have a slight basal pecten and the forewings are linear or lanceolate. The larvae feed variously. Some feed on seeds such as *Anatrachyntis simplex*, which is destructive to sorghum grains in South India. Some cause blotch-mines in leaves of plants such as *Cosmopteryx mimetis* on *Cyperus rotundus, C. bambusae* on bamboo and *C. phaeogastra* on *Lablab niger*. The larvae of *Anatrachyntis falcatella* are predaceous on coccids. It feeds on the scale, *Aonidomytilus albus* seen on tapioca. The larva of *Batrochedra stegodyphobius* inhabits the nests of a social spider *Stegodyphus* sp. in South Africa.

Family Depressariidae

These are small moths generally brownish in colour with apically rounded broad wings. The larvae generally web together or roll the leaves, or sometimes feed on seeds. In India, larvae of *Psorosticha zizyphi* roll or web the leaves of *Zizyphus jujuba*, orange, lemon (*Citrus* sp.) and *Murraya koenigii.*

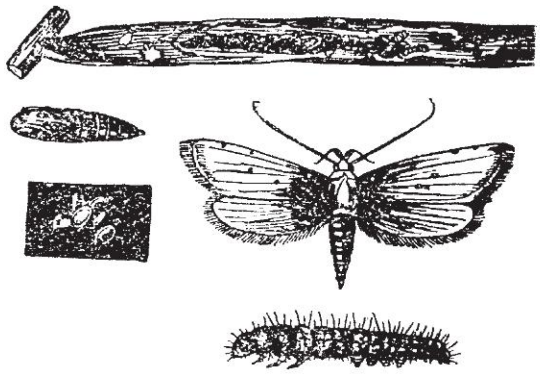
Family Oecophoridae

These are moths without antennal pecten. Larvae are found concealed in shelters or coverings or tunnel in wood, or scraping leaves for food. Larvae of *Procometis trochala* feed on dry fallen leaves of sugarcane. The coconut black-headed caterpillar, *Opisina arenosella,* is a notorious pest of coconut in South India.

THE BLACK-HEADED CATERPILLAR *Opisina arenosella Walker* (Fig. 65.11)

The insect is the most important of the lepidopterous pests attacking coconut in India, Sri Lanka and Myanmar. In India, it occurs on coconut along the coasts of Mumbai, South India, Orissa and Bengal.

The larvae feed gregariously within galleries of silk and frass on the green matter from the lower surface of leaflets. In India, outbreak of the insect occurs during January-May in the West Coast and during April-June in the East Coast. The leaflets are reduced to papery tissues and in the case of severe attack the whole plantation would have the appearance of having suffered from a bad fire. The production of nuts get adversely affected as photosynthetic activity of the palm is much reduced. The fronds become unsuitable for thatching and other purposes.



▲ **Fig. 65.11** *Opisina arenosella. Top—Leaflet showing gallery in attacked portion; Left—Pupa and eggs; Right—Adult and Larva (after T. V.R. Ayyar, 1940)*

The adult moth is greyish white and is nocturnal in habit. The pre-oviposition period is about a day and oviposition lasts for two days. The female deposits eggs in several groups on the undersurface of leaflets of older fronds. A female may lay from 59 to 252 eggs, the average being 137. The incubation period varies from three to seven days, the average being five days. The full-grown larva is greenish-brown with a dark brown head and prothorax and a reddish mesothorax. The larval period ranges from 32 to 55 days, the average being 42 days. The larva pupates in a thin silken cocoon inside the web itself and the adult emerges in about 8 to 14 days.

Longevity of the adult is about 3 to 15 days. A single generation may be completed in about two months. The moths do not migrate. However, they are introduced into or spread to other areas by the larvae and pupae being carried along with coconut leaves and adult moths being carried in the plaited mats used as tops of country boats.

The hosts of the insect are coconut palm (*Cocos nucifera*), palmyrah palm (*Borassus flabelliformis*), Talipot (*Corypha umbraculifera*), *Phoenix sylvestris*, *Caryota urens* and *Livistonia.*

The insects parasitic on *Opisina arenosella* are*, Cotesia taragamae, Bracon brevicornis* (Braconidae), *Goniozus nephantidis* (Bethylidae), *Elasmus nephantidis* (Elasmidae), *Trichospilus pupivora* (Eulophidae), *Antrocephalus renalis* (Chalcididae) and *Xanthopimpla punctata* (Ichneumonidae). The mite *Pediculoides ventricosus* attacks eggs and pupae of the pest. The scarabid beetle *Parena laticincta, Phlaeodromius nigrolineatus* and the reduviid *Sphedanolestes aurescens* are predaceous on the insect.

Control: The infested fronds should be cut and burnt. In case of young trees spray with carbaryl 0.1 %. Root application of monocrotophos has been reported to be effective. A mature dark brown root is selected, cut with a sharp knife and the cut end is immersed in an emulsion containing 20 ml of 1:1 of monocrotophos 36 SC and water secured well in a small polythene bag of size 15 x 10 cm. Periodical release of parasitoids such as *Goniozus nephantidis, Bracon brevicornis, Elasmus nephantidis* and *Trichospilus pupivora* controls the pest. These parasitoids are made available to the farmers by state governments through their parasite breeding centers and commercially by biocontrol laboratories in the country. A bacterium *Serratia* is known to cause disease in the larvae. The exotic tachinid parasitoid *Spogossia bezziana* and an ichneumonid *Eriborus trochanteratus* are also potential bio-control agents.

Superfamily COPROMORPHOIDEA (ALUCITOIDEA)

This includes three families viz. Copromorphidae, Orneodidae (Alucitidae) and Carposinidae.

Family Orneodidae [Alucitidae] (many plume moths)

In this family, both pairs of wings are divided into six or more narrow plume-like structures, each division being fringed with hairs densely along both margins. Larvae of many plume moths are known to cause galls by burrowing into shoots, flower stalks and buds. Larvae pupate in silken cocoons formed on the ground. This family includes a number of species of the genus *Orneodes.*

Family Carposinidae

In this family, M_1 and M_2 are often found wanting in the hindwings. The pests of importance are *Meridarchis scyrodes* and *M. reprobata* with the larvae feeding on fruits of *Zizyphus jujuba* and *Syzigium jambolanum,* respectively.

Superfamily COSSOIDEA

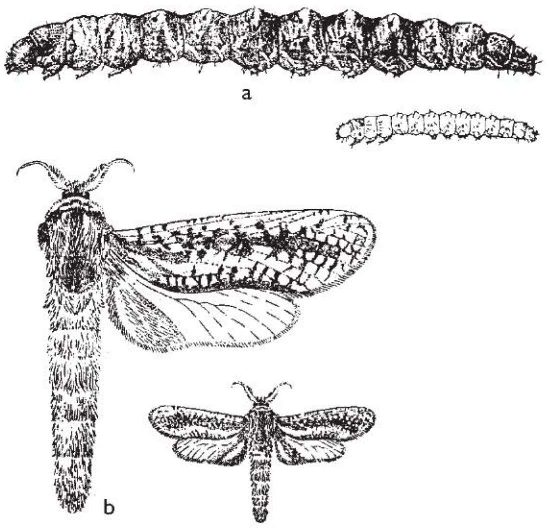
This superfamily is characterised by Cu_2 being present in both pairs of wings and M being furcate within the cell; presence of areole in forewing and absence of haustellum.

Family Cossidae (goat moths, carpenter moths)

These are medium-sized moths, frequently with bipectinate antennae in both sexes; rarely simple but in some males bipectinate for a portion of their length and filiform distally. Proboscis and maxillary palpi are wanting; labial palpi are short and vestigial. R_5 and M_2 are close together or stalked beyond the apex of the discal cell in the hindwings. Adults are nocturnal. Larvae bore large galleries in the wood of forest, shade and fruit trees.

Family Zeuzeridae

Adults are larger than Cossidae. Hindwings with R_5 and M_1 widely separated. Larvae bore into woods of trees. *Zeuzera coffeae* is one of the stem boring species of insects which are important as serious pests of coffee in India. The larva of *Azygophleps scalaris* (Fig 65.12) bores into the stems of green manure plants, viz. *Sesbania bispinosa, S. speciosa* and *S. grandiflora.* In the Soviet Union *Zeuzera pyrina* is a serious pest of apple orchards.



▲ **Fig. 65.12** *Azygophleps scalaris. Larva and Adult (Imperial Entomologist's Report, 1917)*

Superfamily ZYGAENOIDEA

This includes the families viz. Megalopygidae, Heterogynidae, Chrysopolomidae, Metarbelidae, Limacodidae, Zygaenidae Cyclotornidae and Epipyropidae.

Family Epipyropidae

Larvae of epipyropids are parasitic on jassids and fulgorids. *Epiricania melanoleuca* is parasitic on *Pyrilla perpusilla* on sugarcane.

Epipyrops eurybrachydis on *Eurybrachys tomentosa* and *E. fulginosa* on mango hoppers, *Idioscopus* sp. are other parasitic epipyropids in South India.

Family Metarbelidae (bark borers)

The family is confined to tropical region. Larvae are wood borers. Moths are nocturnal. The bark borer *Indarbela tetraonis* is known to attack a number of trees and shrubs such as mango, guava, moringa, rose, orange, citrus, *Zizyphus jujuba*, *Syzigium jambolanum, Phyllanthus emblica, Litchi chinensis, Casuarina equisetifolia. Cassia* sp., *Enterolobium saman, Peltaphorum ferrugineum, Poinciana elata, P. regia, Thespesia populnea, Polyalthia* sp., *kapok* and *Murraya koenigii.* Another species, *Indarbela quadrinotata*, also occurs along with *I. tetraonis.* The larva bores into the stem to about 15 to 25 cm and feeds on the bark mostly during night under shelter of webs covering a considerable part of the stem extending from the bore hole. Only one larva is seen inside a bore hole which is used only as a shelter when it does not feed during day time. There may be about 15 to 30 larvae on a single tree. They eat through the bark into the wood and in cases of severe infestation sap movement is interfered with and the tree ceases to flush. The incidence of the pest is easily made out by the presence of the peculiar winding galleries, generally near the forks or angles on the stem and branches. Larva pupates inside the bore hole and the adult emerges leaving a portion of the empty pupal case protruding out of the bore hole. Injection of kerosene or emulsion of 0.1% chlorpyrifos or endosulfan or monocrotophos or quinalphos into the hole and sealing it with cotton or mud kills the larva. It is also preferable to spray the insecticide on the tree trunk after removing the webs so that effective control can be obtained.

Family Limacodidae (Cochlidiidae or Eucleidae)

Slug caterpillars: Moth is medium sized with stout body. Wings are heavily and loosely scaled. Sexual dimorphism is evident in some cases such as *Spatulicraspeda castaneiceps.* Larva has short, thick, fleshy body, a small retractile head and minute thoracic legs. Larvae mostly possess poisonous spines on the body. Prolegs wanting. Pupa enclosed in a hard round or oval cocoon with an operculum; the cocoon being often irritating to touch. The cocoon may be found on the plants or in some cases inside the soil as in *Thosea* sp.

The castor slug caterpillar *Latoia lepida* is often a serious defoliator of plants and trees like castor, citrus, mango, country almond, pomegranate, coconut, etc. The humped slug caterpillar, whose body is devoid of irritating poisonous hairs occurs on tea and occasionally on castor in South India. The other slug caterpillar pests include *Altha nivea* on castor, *Parasa bicolor* on sugarcane, *Contheyla rotunda* on coconut, *Macroplectra nararia* on coconut and *Inga dulcis, Belippa lalaena* on coffee and cinchona, *Thosea cervina* on tea and *Thosea aperiens* (Fig. 65.13) on sorghum, *Eleusine coracana* (finger millet) and *palmyrah, Thosea triparita* and *T. cana* on castor, *Natada velutina* on mango and *Miresa albipuncta* on *palas.*

1. THE CASTOR SLUG *Latoia lepida* (Cramer)

It is widely distributed in India, Malaysia and Sri Lanka. The moth is short, stout with forewings predominantly green in the middle and brownish at either end. The larvae feed on a variety of plants and inflict severe damage. Young larvae feed gregariously by scraping the undersurface of leaves and cause eventual drying of the foliage. As they grow, they get scattered and feed on entire leaves. Coconut, mango and citrus trees are quite often defoliated and in castor only the skeletonised leaves will remain on the plants. It is a serious pest of sporadic occurrence on castor, pomegranate, citrus, coconut palm, rose, wood apple, country almond, etc.

Life history: The moth lays flat shining eggs in batches of 20 to 30 on the undersurface of leaves. The caterpillars hatch out in six or seven days and start feeding on the leaves. The larva becomes full-grown in about six weeks and measures about 2.5 cm in length. It has four rows of spiny scoli placed laterally and dorsally. Ventrally it is flat and fleshy and thus moves slug-like. The body is greenish above with white lines and possesses spines tipped red or black, which cause irritation and pain by glandular secretion. The larva pupates in a shell-like compact, elliptical, chocolate-brown cocoon, the upper surface being convex and the lower surface flat. The cocoons are seen attached to the stem of castor plants or on the tree trunks of infested trees. Pupal period is about three weeks. The life cycle occupies about ten weeks.

Control: The pest can be controlled by spraying chlorpyrifos 0.02 % or cypermethrin 0.02 %. In South India it is parasitised by *Apanteles* sp., *Chinocentrus* sp. (Braconidae), *Stomatoceras ayyari* (Chalcididae) and *Eurytoma parasae* (Eurytomidae) and preyed upon by larvae of *Euzophera dentilinella.*

2. THE HUMPED SLUG CATERPILLAR *Spatulicraspeda castaneiceps*

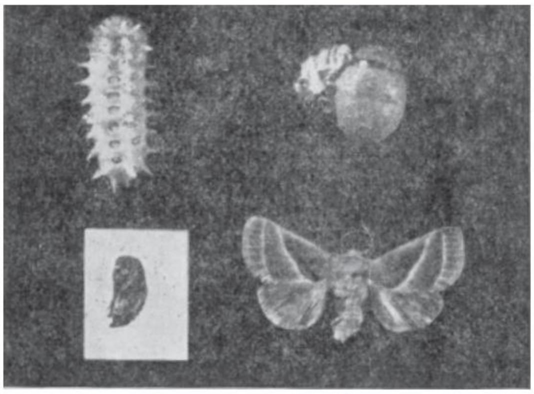
It is one of the smallest slug caterpillars found on tea in Sri Lanka and on tea and castor in South India.

The male moth is dark brown with bipectinate antennae and has a wing expanse of 15 to 17 mm. The female moth is smaller with chestnut brown forewings and smoky black hindwings with a wing expanse of 20 to 22 mm. The female lays about 190 to 200 pale yellow and oval eggs on the undersurface of leaves. The larvae hatch out of the eggs in 5 to 6 days, feed on the leaves and become fully grown in 20 to 22 days. Two distinct forms of larvae—the dark and the light—occur in this species. They are small, dark brown or pale brown colour with a reddish banded or pinkish tinged hump. The larva pupates in a broadly oval globular cocoon having a white colour mottled with various shades of brown. Cocoons are seen on the plant parts. The pupal period is about 13 to 14 days. In Coimbatore it has been observed from June to September. The complete life cycle from egg to adult varies from 38 to 42 days. The larvae are parasitised by *Eucepsis* sp. (Chalcididae), *Apanteles* sp. (Braconidae) and *Chrysis* sp. (Chyrsididae).

3. THE GREEN NETTLE SLUG CATERPILLAR *Thosea aperiens*

The insect (Fig. 65.13) is distributed in India and Sri Lanka. It is found on the cover crop *Dunbaria heynei* in Sri Lanka and on sorghum, *Eleusine coracana* (finger millet), pigeon pea, *Cassia auriculata*, cowpea, tamarind and palmyrah in India.

In South India, especially in Coimbatore district, the pest is known as "leaf scorpion" in view of the severe pain the larva inflicts by its stinging hairs to individuals who come in contact with the slug accidentally. The larva is green with stinging hairs on its body and blends with the colour of the leaf. The larvae defoliate the plants and also cause annoyance. The moth emergence takes place by October-November and the larvae feed on the leaves till December. The full-grown larva aestivates for about eight to nine months and forms the pupa by August-September. Spray application of cypermethrin 0.02 % controls the pest.



▲ **Fig. 65.13** *Thosea aperiens adult, larva, cocoon and pupa (courtesy: B.V. David and T. Santhanaraman, Madras agric. J. 51: 499–502, 1964)*

Family Zygaenidae

This family includes medium-sized moths which are brilliantly coloured and abundant in the tropics. They are diurnal in habits and slow fliers. They resemble the butterflies, a few mimicking some protected butterflies such as *Cyclosia imitans,* which mimics the nymphalid, *Danais aglea*. *Heterusia magnifica* and *H. virescens* are pests of tea in India.

Superfamily PSYCHOIDEA

In this superfamily, proboscis is atrophied with maxillary palpi either wanting or vestigial. Cu_2 usually represented on both pairs of wings; M present within the cell.

Superfamily CASTNIOIDEA

This includes a single family Castnidae comprising of brightly coloured day-flying moths. Found in tropical America and the Indo-Malaysian and Australian regions.

Superfamily TORTRICOIDEA

Family Eucosmidae (Olethreutidae)

Adults are generally small and brownish or grey with patterns on wings. Fringes of long hairs arise on the basal part of cubitus in the hindwing, which is a characteristic feature of this family. Larvae web or roll up the leaves and bore into fruits.

The codling moth *Enarmonia (Carpocapsa) pomonella* is one of the important pests of apple and other fruits in the United States.

In the Orient, the oriental fruit moth *Grapholitha molesta* is a serious pest of peaches and other fruits. The other insects of importance are: *Spilonota rhothia* on guava, *Syzigium jambolanum* and mango leaves; *Grapholitha critica* on *Cajanus cajan*; *Eucosma melanaula* on *Cajanus cajan, Phaseolus mungo, P. radiatus* and *P. aconitifolius*; *Bactra fruculenta* larvae feeding in stems of *Cyperus rotundus*; *Argyroploce illepida* on fruits of *Cassia* sp., *Tamarindus indicus*, *Sesbania* sp.; *A. aprobola* on rose, mango, *Lantana camara*, dahlia, and *Litchi chinensis. Cassia tora* and *Polyalthia longifolia; Laspeyresia koenigana* on *Jasminum sambac* and *Melia azadirachta*; *L. hemidoxa* boring into pepper vine shoot and *L. leucostoma* on tea leaves. Larva of *Ancylis glycyphaga* feeds on the sugary secretion of *Phromnia marginella* (Homoptera).

Family Tortricidae

Moths are small, brownish or grey and when at rest have the wings held roof-like over the body. The long fringe of hairs on the basal part of cubitus in hindwing is wanting. Similarly the first branch of vein M is absent in hindwings.

In South India *Homona coffearia* is well known as a pest of tea. *Homona coffearia*, *H. menciana* and *Adoxophyes privatana* attack *Lantana camara. Cacoecia epicyrta* is a polyphagous species found feeding on *Duranta* fruits, *Lantana camara*, castor, cotton, etc. *Eboda obstinata* rolls the leaves of a common medicinal plant *Cardiospermum helicacabum*. *Cydia perfricta*, *Bactra minima* and *B. venosema* infest *Cyperus rotundus*.

THE NUTGRASS BORER *Bactra minima* Meyrick

The female moth lays two to six green scale-like eggs overlapping on under surface of leaves. The larva on hatching from the egg enters the plant at the base of the stem and causes 'deadheart'. Full-grown larva is dark green and measures 9-12 mm long and pupates in the soil in a tubular white papery cocoon. The egg, larval and pupal periods being, respectively 3.5, 11 and 3.5 days.

Superfamily PYRALOIDEA

Family Thyrididae

The family is characterised by absence of tympanal organs and in hindwings Sc+R is not fused with Rs and Cu_2 is absent. These are different from Pterophoridae in that the wings are not being divided into plumes. In South India the common species found are the leaf webber of *Sesbania bispinosa, Striglina scitaria* and a species of *Dysodia*, the larva of which burrows into tender twigs and causes characteristic rolling of the affected tip in *Cocculus* sp.

THE DAINCHA LEAF WEBBER *Striglina scitaria*

It is distributed in India, Japan, Formosa, Sri Lanka, Myanmar, Andamans, Borneo, New Guinea, Solomons, Australia and Fiji.

In South India it is a pest of importance on the green manure plant, *Sesbania bispinosa* and its outbreak is confined to July-November. In the early stage the larva twists the terminal portion of the leaflet in the form of a small cone and lives inside scraping the green matter. As it grows, it webs together the leaflets and lives inside the tunnel of the web and ultimately pupates inside it. In case of severe attack great loss of leaves results.

Life history: The female moth copulates after two days of emergence. It lays 25 to 30 eggs in groups of two to four in a row on the edges of leaflets. Incubation period is two to three days. The full-grown larva is short, stout, cylindrical, light green in colour and attains a length of 1.6 cm. The larval period ranges from 12 to 14 days. It pupates in a thin silken cocoon inside the webbed leaflets. The pupal period lasts about six to eight days. The adult moth is reddish ochreous; wings evenly striated with brown and an oblique red brown line from the apex of the forewing to inner margin of hindwing before the middle. The total life cycle is about 22 to 24 days.

Apart from *Sesbania bispinosa* it occurs on *Cassia corymbosa, Notonia grandiflora* and *Quisqualis indica.*

Family Hyblaeidae

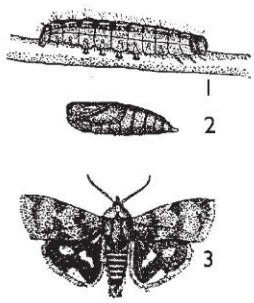
This family is represented by a few Indo-Australian species and superficially resembles noctuids but lack tympana. These insects possess prominent maxillary palps.

THE TEAK DEFOLIATOR *Hyblaea puera* Cramer

The species is recognised as the major pest of teak in India.

Distribution The species is distributed in the oriental and Australian region — (India, Myanmar, Sri Lanka, Java, Papua-New Guinea, Cape York Peninsula of northern Queensland in Australia and the Solomon Islands); Central America - (West Indies); Africa (South Africa and some parts of East Africa).

Life history: Adult moths have a wingspan of 3-4 cm. The forewing is greenish brown and the hindwing with black and orange-yellow markings. Eggs are laid singly on the under surface of tender leaves. About 400-800 eggs are laid by a female. The eggs hatch in about two days. There are five larval instars. Under optimal conditions 10-12 days are required to complete the larval period. But, an average of 21 days has been recorded in the month of November at Dehra Dun. The mature larva descends to the ground on silken threads and pupates in the litter or soil. The pupal period lasts for about a week. The life cycle is completed within 20-35 days and is dependent on temperature conditions prevailing in the area. The larvae also feed on a few plants belonging to the family Verbenaceae and Bignonaceae.



▲ **Fig. 65.14** *Teak defoliator. 1. Larva, 2. Pupa, 3. Adult (T.B. Fletcher, 1914)*

Economic impact: It has been reported that defoliation caused by *H. puera* resulted in a loss of about 44% of the potential volume increment in four to nine year old teak trees grown in plantations. They estimated that the protected trees put forth a mean annual increment of 6.7 m^3/ha compared to the mean annual increment of 3.7 m^3/ha of unprotected trees.

Natural enemies: Several insect parasites, predators including birds and pathogens have been reported to partially manage the pest build up in nature.

Control: No control method is employed as a routine against *H. puera* in plantations. In nurseries, application of insecticides like quinalphos 0.05% has been suggested to control the pest. However, in plantations large-scale use of insecticidal application is discouraged due to environmental considerations. A baculovirus - HpNPV has been reported to be promising against the teak defoliator by the Forest Research Institute, Peechi, Kerala.

Family Pyralidae

This is a large family comprising the subfamilies such as Phycitinae, Galleriinae, Crambinae, Pyralinae and Pyraustinae, which are often treated as families.

Subfamily Galleriinae

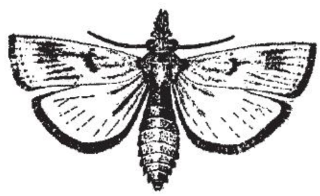
Larvae are known to feed on dry substances, combs of beehives, nests of wasps and sometimes on roots, lower surface of bark, etc. The wax moth *Galleria mellonella* feeds on wax in beehives. The larva pupates in a peculiarly tough cocoon. The lesser wax moth *Achroia grisella* is also known to infest beehives in India. *Achroia innotata lankella* infests the hives of *Apis cerana indica* in South India.

Subfamily Crambinae (grass moths)

These are small moths with narrow and elongated forewings; labial palpi porrect. Eggs are flat and laid in two or more rows overlapping each other, and are not covered with hairs. Larvae remain in silken webs or galleries and bore into stems, crowns or roots of graminaceous plants. The sugarcane stem borer *Chilo sacchariphagus indicus*, the sugarcane shoot borer *Chilo infuscatellus*, the sorghum stem borer *Chilo partellus* and the dark-headed striped borer *Chilo polychrysus*, the pale-headed striped borer *Chilo suppressalis*, the gold-fringed borer *Chilo auricilius* on rice, and the rice root caterpillar *Bissetia steniella* are some pests of importance in India.

1. THE DARK-HEADED STRIPED BORER *Chilo polychrysus*

The insect (Fig. 65.15) is distributed in India, Pakistan, Malaysia, Myanmar, Philippines, Sabah, Thailand, Laos and Vietnam. In India it was first noticed in Kerala in 1956. It occurs on rice in Assam, West Bengal, Kerala, Tamil Nadu and Orissa.



▲ **Fig. 65.15** *Chilo polychrysus adult (M.R.G.K. Nair, Indian Journal of Entomology., 30: 136–141, 1958)*

Damage: In South India it occurs on rice from July to January and is capable of causing up to 60 % loss in a rice crop. The newly hatched larva bores into the outer leaf sheath. In some cases it may first bore through the midrib and reach the leaf sheath, which turns yellowish and then gradually dries up. The larva also bores right into the central shoot and hollows out the internodes and growing points. In a single shoot as many as seven larvae have been noticed. The larvae migrate to adjacent tillers and infest them. Often it causes death of whole tillers. Besides rice, it attacks the weed *Panicum crusgalli.*

Life history: The adult moth has brownish ochreous forewings with six to seven tiny black spots in the centre. In the male it has a raised dark metallic spot in the cell and the antennae are pectinate. Female possesses non-pectinate antennae and is paler in colour. Wing span ranges from 14 to 17 mm in males and 18 to 28 mm in females.

The flat, scale-like, broadly-oval or sub-circular eggs are laid overlapping each other in longitudinal rows of two to four or more on the upper or lower surface of leaves; each group containing 20 to 150 eggs. A female lays about 500 eggs in three days. Incubation period is about six days. The larva becomes fully grown in 23 to 36 days and measures about 21 mm. It has a brownish black head capsule and prothoracic shield, the latter having a yellowish mid dorsal line. There are three dorsal and two lateral purplish brown distinct stripes on the abdomen. Before pupation it makes an exit hole and pupates in a thin silken web. The adult emerges in about four days. The total life cycle is 33 to 46 days.

Control: Chlorpyrifos 0.02 % can be suggested. A braconid *Bracon albolineatus* and an eulophid *Tetrastichus* sp. are parasitic on larvae and pupae respectively.

2. ASIATIC RICE BORER *Chilo suppressalis*

This has a wide distribution in India, China, Hawaii, Indonesia, Japan, Korea, Malaysia, Philippines, Taiwan, Thailand, South Vietnam. In India it is prevalent on rice in Assam, West Bengal, Orissa and Bihar. It is also known as rice stem borer or pale-headed striped borer. Larvae bore into the stems and cause both 'deadhearts' and white ears in the early and later stages of crop respectively.

Life history: The light brown or straw-coloured forewings have black dots in the middle and the hindwings are yellowish white. Longevity of adults is five to eight days. Scale-like, white, translucent eggs are laid in clusters each cluster with 60 to 70 eggs, on the leaves, which hatch in five to six days. The larva becomes fully grown in about 30 days and measures about 26 mm long. The head is yellowish brown and three dorsal and two lateral brownish stripes are seen in the abdomen. Up to ten plants may be attacked by a larva. The pupa is reddish brown and the adult emerges in six days. The total life cycle occupies 41 to 70 days.

Control: In Japan forecasting of outbreaks of the pest is done on a wide-scale and control measures are adopted depending upon the peak periods of moth abundance. Application of a combination product of lindane 4% + carbaryl 4% at 12.5 kg/ha, at 30 and 15 days intervals respectively gives appreciable control of the pest.

3. THE GOLD-FRINGED BORER *Chilo auricilius*

The insect is distributed in India, Sri Lanka, Burma and Taiwan. In India it is prevalent on rice in Assam, West Bengal, Bihar, Gujarat and Orissa. It also occurs on sugarcane in Lucknow (UP), on maize in West Bengal and on sorghum. The larva has five violet lateral stripes. Its feeding characteristics are similar to other rice borers. In India, five to seven generations are seen to occur.

4. THE SORGHUM STEM BORER *Chilo partellus*

The insect has a wide distribution in India, Pakistan, Sri Lanka, Indonesia, Iraq, Japan, Nyasaland and Taiwan. Larvae bore into stems and cause dead hearts. It attacks rice, sorghum, Johnson grass (*Sorghum halepense*), Sudan grass, maize, sugarcane, *Panicum frumantaceum, Eleusine indica, E. coracana, Pennisetum typhoideum*, Job's tears (*Coix lachrymajobi*), *Saccharum sera* and *Polytoca barbata.* In India though it is primarily a pest of sorghum it occurs on rice in Assam, West Bengal, Bihar and Orissa. On sorghum in the early stages it causes "dead hearts". The damage to young plants is far more serious; grown up plants are not killed but suffer in vigour and develop weak heads. It causes damage up to 80 % in a crop.

Life history: The moth is medium-sized and straw coloured. A female lays nearly 300 eggs usually on the underside of leaves near midrib and less frequently on stalk. The eggs are scale-like, flattish, oval, overlapping and laid in batches. These hatch in about seven days and the larvae bite their way into the stem feeding on the internal tissue and killing the central shoot in young plants. The midribs of sorghum plants are often mined by the newly hatched larvae. The larva is cylindrical, yellowish brown with a brown head and pro-thoracic shield and measures about 25 mm long. It becomes fully grown in 28 to 35 days; cuts a hole near one end of its burrow and plugs it with silky material. The pupa is creamy yellow when freshly formed inside the stem and turns reddish brown after about a day. The adult emerges in about seven days. Total life cycle occupies six to seven weeks. In Bihar during winter the larval period ranges from 28 to 193 days and the total life cycle 83 to 210 days.

Natural enemies: Egg parasitoid: *Trichogramma chilonis.* Larval parasitoids: *Apanteles colemani, Cotesia flavipes, C. sesamiae, Bracon chinensis, Chelonus narayani, lphiaulax spilocephalus,* *Rhaconotus roslinensis, Stenobracon deesae, S. nicevillei* (Braconidae), *Goniozus indicus* (Bethylidae), *Trathala flavoorbitalis* (Ichneumonidae) and *Sturmiopsis inferens* (Tachinidae: Diptera). Pupal parasitoids: *Centeterus alternecoloratus, Xanthopimpla punctata, X. stemmator* (Ichneumo-nidae); *Tetrastichus ayyari* (Eulophidae); *Hyperchalcidia sudanensis* (Chalcididae). Adults of the coccinellid beetles *Cheilomenes sexmaculatus* are predaceous on the freshly hatched larvae.

Control: A higher seed rate is adopted and in the early stages affected plants are pulled out and destroyed. After harvest the stubbles should be removed and destroyed. Application of two or three rounds of sprays of carbaryl 0.1 per cent at 15 day intervals from a month after sowing minimises the incidence of the pest. Application of lindane 4%+carbaryl 4% G or endosulfan 4% granule on the 25th and 35th day of sowing at 8 and 10 kg/per hectare respectively in leaf whorls controls the pest.

5. THE SUGARCANE SHOOT BORER *Chilo infuscatellus*

The insect is distributed in India, Pakistan, Indonesia, Philippines, Taiwan, Korea, Afghanistan and the USSR. It is known to infest *Saccharum fuscum, S. spontaneum, Panicum miliaceum,* maize and *Rottboellia compressa.* It is mainly a pest of sugarcane in India. The larva bores into the stem of one to three month old crop and causes dead heart. It damages 10 to 15 % of canes in a crop. However, it has been noticed that as much as 20 to 24 per cent of the primary shoots attacked by the borer revive. The pest occurs during the pre-monsoon and monsoon seasons. High temperatures and low humidity favour rapid multiplication of the pest.

Life history: The eggs are laid as batches on the underside of leaf sheaths in 3 to 5 rows. They are white, flat and overlap each other. A female lays about 400 eggs and in each cluster 8 to 60 eggs may be found. The eggs hatch in about a week and the larvae get scattered about. The larva cuts a hole in the stem somewhere about the ground level and enters the stem. Due to feeding by the larva the central shoot begins to wilt and becomes completely dry in a few days. The affected portion within the stem becomes decayed emitting a foul smell. The larva migrates and attacks a number of shoots. It has a brown head and five violet stripes on the dorsal surface of the body and crescentic or semicircular crochets on the prolegs. The pupal stage lasts for ten days. The adult moth is small, pale greyish brown, the forewings with darker markings especially along the outer edge and the hindwings whitish. Total life cycle occupies about six weeks. In Uttar Pradesh there are six generations of the insect on sugarcane, the life cycle of a generation being 24 to 33 days in summer and 154 to 277 days in winter.

The eggs are parasitised by *Trichogramma chilonis* and *Telenomus beneficiens*, the larvae by *Cotesia flavipes, Bracon chinensis, Stenobracon deesae, S. nicevillei, Goniozus indicus* and *Gambroides javensis,* and the pupae by *Tetrastichus ayyari.*

Control: The infested tillers may be collected and destroyed. Avoiding late planting, high seed rate, trash mulching and earthing up the crop usually a month after planting, help in minimising the damage. Application of an emulsion of lindane or chlorpyrifos (20% EC 5 litres in 1500 litres of water) over the setts in furrows at the time of planting affords protection. Soil application of granular lindane or cartap hydrochloride at 1 kg a.i./ha at planting reduces shoot borer damage in endemic areas. Another application at 45th day would be necessary for late-planted crop. Cartap hydrochloride 4 G or chlorpyrifos 10 G or lindane 4% + carbaryl 4% G at 1 kg a.i./ha as whorl application at 35th and 65th day are effective. Application of lindane 10 per cent granule at 12 kg/ha at 35th day of planting also controls the pest. Release of the egg parasitoid *Trichogramma chilonis* is also effective. Granulosis virus has also been found promising. Release of gravid females of the tachinid *Sturmiopsis inferens* at 125/ha at 45th day of crop growth has been found promising. The varieties *Co 853, Co 987 and Co 1007* are resistant to the attack of shoot borer.

6. THE SUGARCANE INTERNODE OR STEM BORER *Chilo sacchariphagus indicus*

The insect is found in India, Pakistan and Sri Lanka. In India it is considered to be a major pest of sugarcane. The pest appears late in the growing phase of the crop and is active in the post-monsoon and harvest periods. The larvae infest the soft internodes, 80 % of attack is being noticed generally on the first five internodes. The attack is severe on autumn-planted crop than spring-planted crop. Attacked canes lose weight considerably and the juice quality also deteriorates. About 20 to 50 % of canes are infested. Low temperature and high humidity are favourable for the multiplication of the insect.

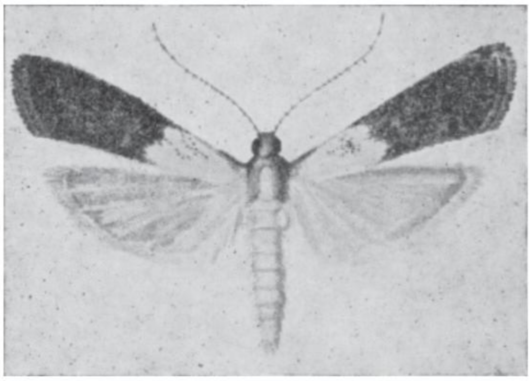
Life history: The eggs are laid in batches on the sheathing leaves and 9 to 11 white, scale-like eggs in two rows are seen in each batch. The larvae that hatch out from the eggs in about three days bore near the nodes and feed on the inner contents making the tissue turn red. The bore hole is plugged with excreta and the larvae migrate and attack a number of nodes. The larva is white with dark spots on the body and a brown head. The crochets are circular. In about a month the larva becomes fully grown and pupates in the leaf-sheath. The adult is pale brown with white hindwings, and emerges in a week. The life cycle occupies about six weeks.

Eggs are parasitised by *Trichogramma chilonis* and *Telenomus* sp., larvae by *Stenobracon deesae, S. scripophagae, Xanthopimpla nursei, Rhaconotus roslinensis, Goniozus indicus* and *Cotesia flavipes*; the pupae by *Trichospilus diatraea* and *Xanthopimpla stemmator.*

Control: Periodical collection and destruction of egg masses and inundative release of the parasitoid *Trichogramma chilonis* at 50000 parasitoids/ha/week from the fourth up to eleventh month after planting affords protection. Resistant varieties are Co 285, 453, 513, 617, 853, 915, 1007, 1287, 6806 and CoJ 46.

Subfamily Phycitinae

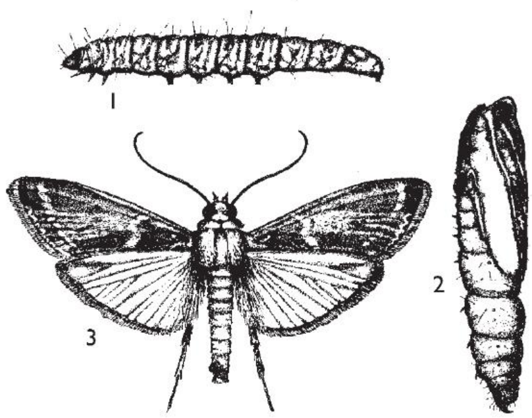
The moths are small, delicate insects with elongate forewings having no R_5. The hindwings are broad and bear pecten of hairs on the dorsal side. Males are characterised by swollen basal antennal segment. Larvae feed in various ways. Larva of the Indian meal moth *Plodia interpunctella* (Fig. 65.16) is destructive to maize, figs and seeds of various kinds. *Cadra cautella* is a serious pest of stored products feeding on all types of grains in granaries, warehouses, markets and houses. Larvae of *Phycita infusella* attack top shoots of cotton. Larvae of *Elasmopalpus jasminophagus* web together leaves, shoots and flower heads and feed on them. The white borer *Saluria inficita* bores into stems of *Eleusine coracana, Setaria italica* and rarely rice. *Etiella zinckenella* is a pod borer on various pulses and leguminous plants. Larvae of *Euzophera perticella* bore into stems of brinjal, potato, chillies, etc. *E. punicella* infests pomegranate. *Phycita clientella* is a leaf folder on brinjal and *P. orthoclina* bores into tamarind fruits. *Hypsipyla robusta*, known as the Oriental toon moth, is a shoot borer of some forest trees. Larva of *Anonaepestis bengalella* is a serious fruit borer pest of custard apple in India. *Nephopteryx eugraphella* is a leaf webber on sapota. A few are beneficial as predators and weed killers. In North America larvae of *Laetilia coccidivora* is predaceous on coccids. In South India larva of *Euzophera dentilinella* is predaceous on pupae of the castor slug *Latoia lepida,* and *Lymantria serva.* The cactus moth, *Cactoblastis cactorum,* has exercised effective control of the prickly pear in Australia and India.



▲ **Fig. 65.16** *Plodia interpunctella the Indian meal moth, adult (courtesy: USDA, Washington)*

1. THE TAMARIND FRUIT BORER *Phycita orthoclina*

The insect (Fig. 65.17) has so far been reported from Marquesas island and India. In India it has been noticed to cause considerable damage to tamarind fruits and dry fruits and seeds of *Bombax malabaricum* in Kerala. Larvae feed on the pulp and their excrement, cast skins and webbings render them unfit for any culinary purpose.



▲ **Fig. 65.17** *Phycita orthoclina: 1. Full-grown larva, 2. Pupa, 3. Adult. C.N. Oommen, Indian J. entomol, 24: 189, 1962)*

A female lays up to 190 eggs in about three days singly on the pulpy portion inside the rough shelled pods, through cracks and crevices found on them. The egg is flat, broadly oval and white in colour. The eggs hatch in about four to five days. The larva bores into the fruit pulp and remains in a silken web. It becomes fully grown in 27 to 40 days. The fully grown larva is cylindrical, pink and measures 14 mm long. It has a reddish brown head and light brown pro-thoracic shield. It pupates in a silken cocoon inside the infested pod in between the rough shell-like rind and the pulp or inside the seeds. The adult moth emerges in about six to eight days.

2. THE PULSE POD BORER *Etiella zinckenella*

The insect is known as the lima bean pod borer and is distributed in the USA, Mexico, West Indies, South America, Europe, Egypt, Indonesia, India, Japan and Australia. The injury is caused by the larvae, which bore into the pods and feed on the developing seeds. One or rarely two larvae may be seen in a pod. After feeding the larva moves to another pod. As it feeds on the grains, the yield is reduced considerably.

The moth is greyish brown with a white line on the anterior margin and a transverse yellow band, and pale hindwings. The female lays the whitish, elliptical eggs singly or in small groups on developing pods. The incubation period is five days. The newly hatched larvae are positively phototrophic. Larva feeds inside the pod and becomes full-grown in about 9 to 17 days. It is green with greenish head and fine black spots on the pro-thorax. Before pupation it turns pink. It pupates in the soil at a depth of 1 to 5 cm in an earthen cocoon or in the debris. The adults emerge in about 9 to 72 days depending on the weather conditions. The life cycle is completed in about 22 to 24 days at 25° C and at lower temperatures and depending on availability of food plants it gets prolonged.

It infests *Tephrosia candida, T. noctiflora, T. purpurea*, horsegram (*Dolichos biflorus*), cowpea (*Vigna sinensis*), lablab (*Lablab niger*), redgram (*Cajanus cajan*), sunnhemp (*Crotalaria juncea*), etc.

Two or three applications of carbaryl at 1 kg a.i./ha per application have been suggested.

3. THE BRINJAL STEM BORER *Euzophera perticella*

It occurs throughout the plains of India. The larva bores into the stem in the leaf axil closing the hole with excreta and frass. It enters the main stem and causes either stunting of growth or withering of plants. Usually its infestation is noticed in the late stage of the crop. It infests brinjal, potato, chillies, tomato and *Solanum aviculare*.

The moth is small and has greyish brown forewings with transverse lines in the middle, and white hindwings. Moths appear towards the end of March and soon after mating the females start laying eggs. Creamy white, elongated flat eggs are laid on tender leaves, petioles and branches singly or in batches. Incubation period is three to ten days. The larva bores into the stem and becomes fully grown in 26 to 58 days depending on factors like temperature. It pupates inside the tunnel in a thin silken cocoon and emerges in 9 to 16 days.

The insect is active from March to October and from November to the beginning of March it hibernates as larva.

4. THE SAPOTA LEAF WEBBER *Nephopteryx eugraphella*

This is an important pest on sapota. The larva constructs a tunnel of webs and frass and feeds on the green matter of leaves. Leaf buds, flower buds, tender leaves and fruits are attacked. Sometimes three or four larvae may be seen in a tunnel. Apart from sapota it is known to infest cured tobacco and *Mimusops elengi*.

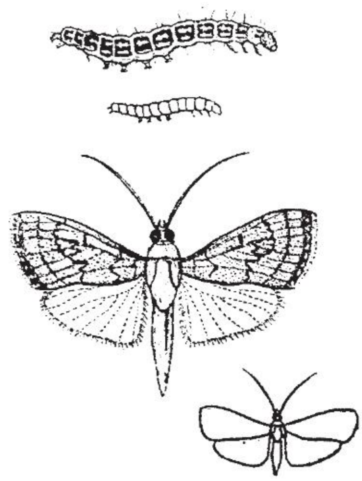
Moth is grey in colour and lays pale yellow oval eggs in groups of two or three or singly on leaves. The number of eggs laid by a female varies considerably, the maximum being 226 in seven days. Full-grown larva is 25 mm long, slender and pinkish with few longitudinal close-set lines on the dorsal surface. It pupates on the leaf web itself. The egg, larval and pupal periods occupy 3 to 5, 17 to 32 and 7 to 11 days respectively. Total life cycle is 32 to 45 days. Removal and destruction of affected portions and spraying monocrotophos or cypermethrin may be useful.

Subfamily Pyralinae

This subfamily is a small group which is found widely distributed in the tropics. The moths are small and the larvae feed on dried vegetable matter, wax, etc. Larvae of *Pyralis farinalis* feed on stored potato and that of *Hypsopygia mauritialis* feed on wax in wasp nests.

THE TEAK SKELETONISER *Eutectona machaeralis* Wlk. (Fig. 65.18)

It is popularly known as skeletoniser because the larvae feed on all leaf tissues leaving only a network of veins, which looks like a skeleton. This pest is invariably found along with the teak defoliator, *Hyblaea puera*. Teak is the chief host but some species of *Callicarpa* serve as alternate hosts.



▲ **Fig. 65.18** *Teak skeletoniser. Top: Larva and Bottom: adult (from Indian Museum Notes, Calcutta)*

Distribution: Indo - Malayan Region up to Australia.

Life history: Moths are small with a wing span of 1.9 - 2.6 cm. The colour and pattern of the wings vary with temperature and humidity. Mating takes place in the night after emergence. Eggs are laid in one to four days after pairing. Oviposition period lasts for one to two weeks and the female lays around 250 eggs. Eggs are laid singly on the upper or underside of the leaf and hatch in about three days. There are five larval instars. Larva feeds on the tissue between the network of veins thereby skeletonising the leaf which turns brown. The mature fifth instar larva pupates on green teak leaves or in fallen leaves spinning a thick opaque cocoon. Total life cycle is about 30 days.

Hibernation is observed in regions with a winter climate, in which the pre-pupal stage is prolonged. The population dynamics of *E. machaeralis* has not been studied in detail. Migration of moth and diapause of larvae have been suggested.

Natural enemies: A total of 75 parasites, 31 insect predators, 38 spiders and several bird predators have been reported.

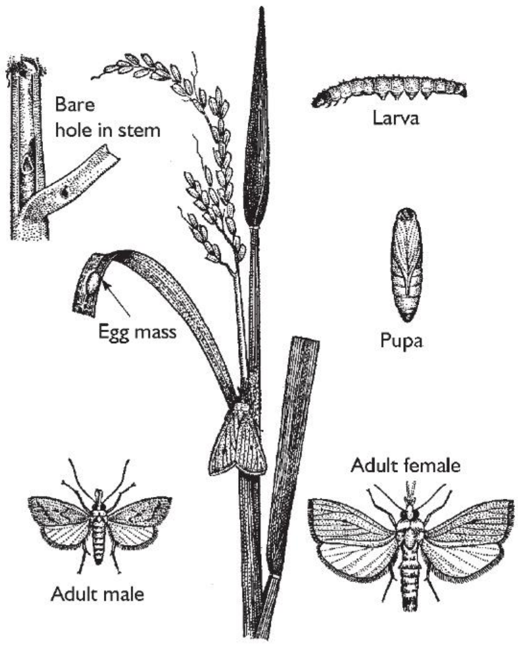
Control: Usually a combination of biological and silvicultural methods has been suggested for the management of the pest, but seldom followed. Release of parasites like *Trichogramma* spp. have been tried, but not practiced. In nurseries application of 0.05% quinalphos will contain the pest.

Subfamily Schoenobiinae

These are characterised by proboscis being vestigial or absent and fringed hindwings. The eggs are covered with hairs from the anal tuft of the female. This subfamily includes *Scirpophaga incertulas*, the yellow borer of rice, which is one of the most important pests of rice in India. *Scirpophaga innotata* is the white rice borer. *Scirpophaga excerptalis* is the top borer of sugarcane in India and Pakistan.

1. THE YELLOW BORER OF RICE *Scirpophaga incertulas* (Fig. 65.19)

The insect is widely distributed in all Asian countries and is commonly known as yellow borer of rice, paddy stem borer or rice stem borer. The insect being monophagous is one of the serious pests of rice in India. Its infestation causes drying up of the central shoots or "dead hearts" in young plants and "white ears" on drying of the panicles in older plants. In South India, the incidence is serious during October to January.



▲ **Fig. 65.19** *Scirpophaga incertulas (T.B. Fletcher, 1914)*

Life history: The female lays the eggs early at night near the tip on the upper surface of tender leaf in small masses and covers them with a felt-like buff coloured mass of hairs and scales. The number of eggs in each egg mass ranges from 15 to 80. Two or three clusters of eggs are laid by a female. Eggs hatch in about five to eight days. The first instar larva measures 1.5 mm long and is pale white in colour with dark brown head and pro-thoracic shield. The newly hatched larvae move downward and wander about on the plant surfaces for one or two hours. They may hang down by silken thread, get blown off to other clumps or land on the water of paddy field, swim freely (as they have an air layer next to their skin) in search of seedlings and get to the plants. They enter the leaf sheath and feed upon the green tissues for two to three days, and then bore into the stem near the nodal region. They disperse from one plant to another, and usually only one larva is found inside a stem. Sometimes up to four larvae have been noticed in a stem. Often it comes out after a week, makes a case with leaf bits, drifts on water and attacks a fresh plant. There are about six instars and the full-grown larva measures 20 mm long. It is white or yellowish white with a well-developed pro-thoracic shield. Abdominal prolegs are reduced and the crochets are short and stout, arranged in a single narrow ellipse. The larval period is 33 to 41 days. Before pupation, the exit hole is covered with thin webbing and a white silken cocoon is formed, in which it pupates. The dark brown pupa is 12 mm long and the moth emerges in six to ten days or in about a month depending on the climate. The moths are capable of emergence through 12 cm of water in the field. Female moth is bigger than male. The female has bright yellowish brown forewings with a clear single black spot and the anal end having tufts of yellowish hairs. The male is pale yellow and the spots on the forewings are not conspicuous.

They are attracted to light, especially the females, which come from as far as five miles. The female to male ratio is 2:1. Three to five (average four) generations or broods of the yellow borer occur in South India. October to December, characterised by cold weather, high humidity and low temperature are the crucial months.

Natural enemies: The following are the various natural enemies in the different life stages of the pest in India.

Parasites

Eggs: Tetrastichus schoenobii, Tetrastichus sp. (Eulophidae); *Telenomus beneficiens, T. dignoides, T. dignus, T. rowani* (Scelionidae); *Trichogramma chilonis, T. japonicum, T. nanum.* (Trichogrammatidae).

Larvae: Goniozus indicus (Bethylidae); *Apanteles ruficrus, A. schoenobii, Bracon chinensis, Chelonus* sp., *Orgilus* sp., *Rhaconotus oryzae, R. schoenobivorus, R.* sp. nr. *signipennis, Shirakia schoenobii, Stenobracon nicevillei* and *Tropobracon luteus indicus* (Braconidae); *Elasmus albopictus* (Elasmidae); *Amauromorpha accepta accepta, A. a. metathoracica, A. a. schoenobii, Apsilops* sp., *Charops bicolor, Ischnojappa luteator, Gambroides javensis* and *Temelucha* sp. nr. *pestifer* (Ichneumonidae); *Platygaster oryzae* (Platygasteridae); Nematoda: *Agamermis* sp., *Hexamermis* sp.

Pupae: Elasmidae: *Elasmus albopictus;* Eulophidae: *Tetrastichus ayyari;* Ichneumonidae: *Ischnojappa luteator, Temelucha pestifer, Xanthopimpla emaculata*

Predator: Carabidae: *Chlaenius* sp.

Control: Removal and destruction of rice stubbles from field and collection and destruction of egg masses lowers infestation. Clipping the tip of the seedlings prior to transplantation aids in the elimination of egg masses. Moths may be collected by setting light traps and killed. An economic threshold level of 10% dead heart in vegetative stage and presence of 1 moth or 1 egg mass/sq. m. in the ear bearing stage has been suggested for adoption of chemical control. Spraying of fenthion or fenitrothion or endosulfan or phosalone or monocrotophos or etofenprox or cartap hydrochloride or chlorpyrifos or phenthoate at 0.5 kg a.i./ha, or fipronil 5 SC at 1 litre/ha thrice, the first in the nursery a week prior to pulling out the seedlings, the second a fortnight after transplantation, and the third at the shot blade stage affords protection. In the long duration variety, an additional application may be necessary a month after the second round of treatment. Application of granular insecticides such as lindane granule at 2.5 kg a.i./ha or any of carbofuran, cartap chloride, chlorpyrifos, quinalphos and phorate at 0.75 kg a.i./h, or lindane 4% + carbaryl 4% granule at 1 kg a.i./ha or fipronil 0.3% G at 25 kg/ha over a thin film of standing water in the rice field at 20 day intervals commencing 15 days after transplantation up to shot blade stage affords control. Seedling root dip treatment, for 12-14 hours before transplanting, in 0.02% emulsion of chlorpyrifos gives protection up to 30 days against stem borer, gall midge and leaf hoppers.

2. THE SUGARCANE TOP BORER *Scirpophaga excerptalis*

It is one of the important pests of sugarcane in India and Pakistan. In India it occurs in all cane growing areas.

A reddish brown charred and sometimes curved 'deadheart', leaves with shot holes and galleries in the midrib of leaves are the symptoms by which top borer attack can be detected. Top buds give rise to side shoots forming a bunchy top due to cessation of growth. It usually affects the crop in the later stages of growth and continues till harvest. It accounts for a loss of about 20 % maturity in grown up canes and reduction in juice quality.

Life history: The moths are milky white in colour. The female lays a large number of elongate and oval eggs in clusters mostly near midribs and covers them with buff coloured hairs from the hind end of the abdomen. The eggs are dull white and in each egg mass 9 to 79 eggs are seen overlapping each other. Incubation period is 6 to 11 days. The larvae tunnel into the midrib of leaves and the second to fifth leaves bear the red markings of feeding. The larva enters the shoot through holes bored on the sides. After sometime a number of small holes can be seen on the central leaves. The larva is dull creamy yellow and becomes full grown in 25 to 42 days. It pupates inside the bore hole and the adult emerges in 12 to 21 days. The total life cycle occupies about 45 to 84 days. In Tamil Nadu from August to February three broods are completed and between April and June one more brood is noticed. There are five generations in Punjab and Bihar and six in Uttar Pradesh. The natural enemies of the insect include the egg parasites *Telenomus beneficiens* and *Trichogramma chilonis* and the larval parasites *Cotesia flavipes, Elasmus zehntneri, Rhaconotus scirpophagae, Shirakia* sp., *Stenobracon deesae, S. nicevillei, Tetrastichus* sp. and *Gambroides javensis. G. javensis* was reared and released successfully on field scale at Pugalur in Tamil Nadu.

Control: Biological control by releasing the parasitoid *Gambroides javensis* was found promising. Soil application of carbofuran at 2 kg a.i./ha or phorate at 1 kg a.i./ha for the third brood during first week of July has been found effective.

Subfamily Nymphulinae

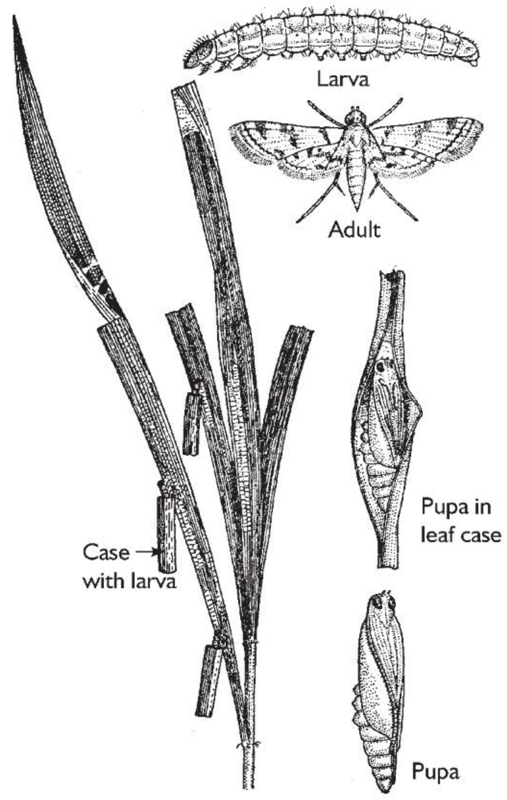
Larvae are aquatic possessing breathing gills and feed on aquatic plants. *Parapoynx stagnalis* sometimes causes severe damage to rice. The larvae remain in cases made up of leaf bits and feed by scraping the leaf tissue. *P. fluctuosalis* also attacks rice in India. The other species known to infest rice are *Nymphula nymphaeata* in Italy and Hungary, *N. enixalis* in Malaysia and *N. vittalis* in Japan.

THE RICE CASEWORM *Parapoynx stagnalis*

The insect (Fig. 65.20) is distributed in India, Pakistan, Sri Lanka, Australia, Malaysia and the Philippines.

This is a pest of irrigated rice crop and infestation seldom becomes serious. The larva cuts the leaf blades into short lengths and constructs a tubular case inside which it remains and feeds on the foliage scraping the green matter in patches leaving characteristic white marks. The larva mostly feeds on the undersurface of leaves leaving the upper epidermis alone intact which appears white. Rice hills infested severely become stunted and often get completely killed. The damage is severe in the early stage of transplanted crop.

Life history: The adult is a small, delicate moth having white wings speckled with pale brown wavy markings. Wing expanse is 22 to 30 mm. Its longevity is two to eight days. The female lays eggs singly on the leaves of rice and grasses. A female may lay about 50 eggs. The incubation period of the egg is two to six days. The larva lives inside a tubular case made up of cut leaf bits and



▲ **Fig. 65.20** *Parapoynx stagnalis (ibid)* carries it as it moves. With each moult, as it grows, the leaf-case is also changed. The larva becomes full-grown in 14 to 20 days. It is light green in colour with a light brownish-orange head and measures about 15 mm long. The larva is semi-aquatic in habit. It has filamentous gills on the sides of its body and the necessary oxygen is obtained from the water in the leaf-case. This water in the leaf-case is often replenished with fresh water by the larva coming to the surface of water in the field. It pupates inside the leaf case, which remains attached to the base of the tillers. The adults emerge in four to seven days and are capable of emerging through water. The total life cycle occupies about 19 to 37 days. The insect, apart from rice, also breeds on grasses like *Eragrostis* sp., *Paspalum* sp. and *Panicum* sp.

Control: Dislodging the leaf-cases from the plants by passing a rope and draining the water at a later stage will be helpful. The addition of a small quantity of kerosene to form a thin film on water kills the larvae. Draining the field for a short period of two to three days deprives the larvae of oxygen and thus the larvae get eliminated successfully. Sprays of endosulfan or monocrotophos or methyl parathion or quinalphos at 0.5 kg a.i./ha is recommended.

Subfamily Pyraustinae

This subfamily contains a large number of forms, which are abundant in the tropics. Larvae of these insects feed variously by remaining in silken web amongst spun-up leaves, stems, fruits, or roots. In the USA, *Ostrinia nubilalis* is the most notorious pest of corn and is known as the European corn borer. In India the family is well represented and a large number of them are pests of economic importance on a variety of crops. The following are some important pests in India.

1. THE SESAMUM LEAF WEBBER *Antigastra catalaunalis*

The insect occurs throughout India, Myanmar and Sri Lanka. The larvae feed on tender foliage or web the leaves together and feed on them. They also bore into the tender shoots or capsules and destroy the contents. In cases of severe infestation yield is affected considerably.

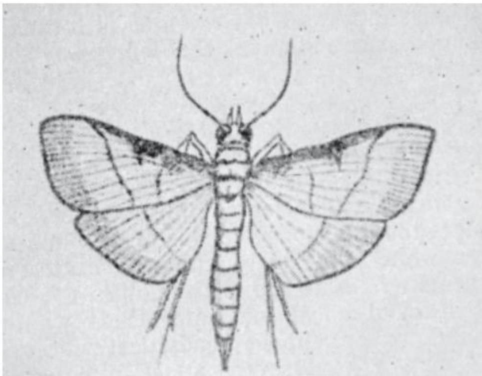
Life history: The moth is small, brown with pale yellowish brown elongate wings. It lays 100 to 130 shining, flat eggs singly on the tender portions of plants. Incubation period of the eggs is four to five days. The larvae become full-grown in 11 to 16 days. The full-grown larva measures 20 mm long, pale green with black head and tubercles on the body surface from which arise thin hairs. It pupates in the leaf fold itself in a thin transparent pale white silken cocoon. Pupa is pale whitish green and the moth emerges in four to seven days.

Control: Clipping the affected portions and destroying the larvae may be done. Spray application of phosalone 0.07% or methyl parathion 0.025% or carbaryl 0.1% or dusting carbaryl 5% or methyl parathion 2% dust is recommended. In nature, larva is parasitised by an ichneumonid *Trathala flavoorbitalis*.

2. RICE LEAF ROLLER OR RICE LEAF FOLDER *Cnaphalocrocis medinalis* (Fig. 65.21)

Distribution: The insect is seen in Sri Lanka, China, India, Japan, Madagascar, New Guinea, Pakistan, Sabah, Samoa and throughout South-East Asia.

Damage: The larva fastens edges of a tender leaf together and lives inside the rolled leaf by scraping the green tissues. Sometimes the tip of a leaf is drawn and fastened to the basal part of the leaf, which gives it a rolled appearance. The infested leaves turn whitish and in cases of severe attack the whole field appears scorched and sickly. The infestation starts a month after transplantation and may continue up to the boot leaf stage of the crop. The growth of tillers gets affected considerably and results in a loss ranging from 5 to 60 per cent of the crop. It is a sporadic pest on the crop.



▲ **Fig. 65.21** *Cnaphalocrocis medinalis adult*

Life history: The moth is small, brownish-orange coloured with light brown wings having two distinct dark wavy lines on forewings and one line on hindwings, the outer margin characterised by a dark brown to grey band. It lays flat oval yellowish eggs singly or in pairs on the undersurface of tender leaves which hatch in four to seven days. The larva feeds inside the leaf fold and becomes full-grown in 15 to 27 days. It is pale yellowish green and measures about 16 to 20 mm long. It pupates inside the leaf roll and the adult emerges in six to eight days. The life cycle occupies 26 to 42 days.

Control: The ichneumonid *Xanthopimpla emaculata* is parasitic on the insect in India. Removal of grasses from bunds should be done as the insect breeds on them. Sprays of phosalone, carbaryl, monocrotophos, etofenprox, cartap hydrochloride, chlorpyrifos, methyl parathion, quinalphos or fenthion at 0.5 kg ai./ha or fipronil 5 SC at 1 litre/ha is recommended.

3. THE CASTOR SHOOT AND CAPSULE BORER *Conogethes punctiferalis*

Distribution: The insect is seen in Australia, Myanmar, Sri Lanka, China, Indonesia and Malaysia.

Damage: It is primarily a pest of castor and infests the plant at the flowering stage. The larvae bore into the capsules and damage the seeds, and also into the peduncle. Occasionally the leaves are bored at the junction of the petiole with the lamina of the leaf. In broad-leaved variety even the thick midrib or vein of the leaf is attacked. On castor it attacks 16.4 to 82.6 % panicles. Panicles on which the capsules are set close are damaged severely than lax panicles. Apart from castor it feeds on mango inflorescence, sorghum ears, fruits of guava, peaches, cocoa, pear, avocado and mango, and bores into the stem of cardamom, ginger and turmeric.

Life history: The moth is medium-sized, pale yellowish with small black spots on the wings. A banded form *C. punctiferalis* var. *semifascialis* is also sometimes noticed on castor. The moth lays the eggs singly or in groups of two or three at night mostly in between the warts or just below the style on the ovary of the flowers and on the developing capsule up to the stage it is half mature. Rarely are they laid on unopened male flowers and the leaf axil. Egg is pink, oval, flat with rough surface, 0.5 mm in diameter, and as much as 20 eggs are laid on a single panicle. Incubation period is six to seven days. The larva becomes full grown in 12 to 16 days. It measures 20 to 24 mm long. Its body is pale greenish with pinkish wash dorsally, head and prothoracic shield brown and body covered with minute hairs arising on warts. Throughout larval period it remains in concealment under a cover of silk and frass or excreta, which extend between capsules. It pupates in a thin silken cocoon inside the burrow and the adult emerges in seven to ten days. Total life cycle is 25 to 33 days.

Its food plants in India are castor, arrow root, ginger, turmeric, guava, mulberry, pomegranate, mango, sorghum, peach, pear, sunflower (*Helianthus annuus*), *Caesalpinia bonducella*, cotton, tamarind, cardamom, hollyhock (*Althaea rosea*), loquat, jack, avocado, *Amaranthus* and *Anona cherimolia*.

Control: The natural enemies of the insect in India include *Apanteles* sp., *Eriborus trochanterata, Theronia inareolata* and *Bracon brevicornis* on larva and *Brachymeria euploeae* on pupa. Collection and destruction of affected capsules minimises damage. Application of three rounds of parathion 0.05% or malathion 0.1% or endosulfan 0.07% or chlorpyrifos 0.02% or fenthion 0.05% at 21 days interval from the time of formation of inflorescence minimises the damage by the pest on castor.

4. THE WEB WORM *Cryptoblabes gnidiella*

Distribution: The insect occurs in Sri Lanka and India.

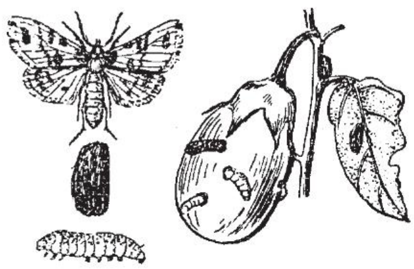
Damage: The larvae infest the ears of sorghum, *Pennisetum typhoideum, Eleusine coracana* and the panicle of castor. The larva remains near the rachis inside a thin web and webs together adjacent grains and feed on them.

Life history: The moth is small with brown forewings and light brown hindwings. Wing expanse is 15 mm. Adults live for three to nine days. They lay flattened, somewhat triangular oval, creamy white eggs on the lemma of newly opened flowers and rarely on the glumes and rachis. A female lays about 14 eggs in three days. Incubation period is three days. The larva becomes fully grown in 19 to 22 days. It is narrow, slender, greyish in colour with a dark brown mid dorsal line and lateral lines. It measures about 12 mm long. It pupates in a thin silken cocoon and the adult emerges in 7 to 20 days. The total life cycle is 31 to 43 days. It occurs during summer and winter seasons.

Control: Dusting with carbaryl 10% dust or methyl parathion 2% dust is recommended as a preventive measure.

5. THE BRINJAL SHOOT AND FRUIT BORER *Leucinodes orbonalis* (Fig. 65.22)

Distribution: The insect in found in Myanmar, Sri Lanka, Congo, Malaysia and South Africa.



▲ **Fig. 65.22** *Brinjal fruit borer- Damage caused and life stages Left: top Adult; middle cocoon; bottom Larva; Right: Fruit damaged by larvae*

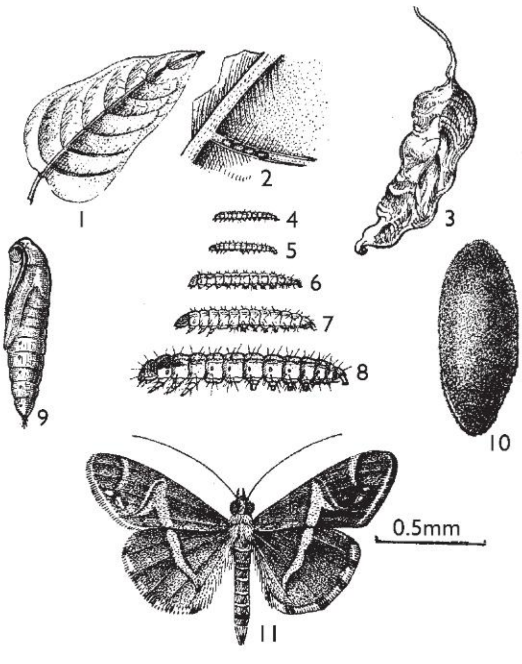
Damage: It is mainly a serious pest of brinjal (*Solanum melongena*) in India. Sometimes it causes large scale destruction of potato (*Solanum tuberosum*) crop in Karnataka, Bihar and around Pune. The larva bores into petiole and midrib of large leaves and tender shoots and causes “dead hearts.” In the later stage it also bores into flower buds and fruits. The flower buds are shed due to attack. The inside of the fruit is damaged considerably and the entry hole can be seen plugged with excreta. Attacked fruits become unfit for consumption and marketing. Its infestation on brinjal crop can be as high as 70 % and on potato crop up to 40 %.

Life history: The moth is medium-sized with white wings having triangular brown and red markings on the forewings. The female lays flat white eggs singly on tender portions of plants or fruits and about 250 eggs are laid by a female. The incubation period is three to five days. The full-grown larva measures 16 to 20 mm and is pink with a brown head and sparsely distributed hairs all over the body arising on warts. Larval stage is about 15 days. It pupates on the stem or fruit in a grey tough cocoon and the adult emerges in six to eight days. In India it infests *Solanum melongena, S. tuberosum, S. xanthocarpum, S. indicum, S. nigrum, Momordica charantia* (bittergourd), pea pods, etc.

Control: Removal and destruction of affected parts and spraying with phosalone 0.07% or carbaryl 0.1% or cypermethrin 0.025% or profenofos 0.05% is suggested. Its natural enemies include *Trathala flavoorbitalis, Pristomerus testaceus* (Ichneumonidae), *Bracon* sp. nr. *chinensis, Shirakia schoenobii* and *Iphiaulax* sp. (Braconidae).

6. THE AMARANTHUS LEAF CATERPILLAR *Spoladea recurvalis (F.)* (Fig. 65.23)

Distribution: The insect is found in Asia, Africa, Australia, Hawaii Islands, New Zealand and in the tropical and sub-tropical regions.



▲ **Fig. 65.23** *Spoladea recurvalis: 1. Amaranthus leaf with an egg mass in the groove of the leaf vein, 2. Enlarged eggs in the groove of the leaf vein, 3. A leaf web, 4-8. 1st, 2nd, 3rd, 4th, 5th instar larvae, 9. Pupa; 10. cocoon, 11. adult (N.S. Bhattacherjee and M.G. Ramdas Menon, Indian J. Entomol., 26: 176–183, 1964)*

Damage: It is mainly a serious pest of *Amaranthus* throughout India although it occurs on a number of flowering plants and vegetable crops. Larvae web leaves with silvery threads and feed on leaves by scraping the green tissues leaving plenty of excreta. In cases of severe attack the leaves dry up and the plants may die.

Life history: The moth is small with dark wings having wavy white markings. The female lays the eggs in the grooves of leaf veins. As many as 156 eggs may be laid by a female. Incubation period is three to four days. Larva undergoes five moults and becomes full-grown in 12 to 15 days. The larva is green with a light brown head. In the last instar it turns pink and pupates in the soil in an earthen cocoon. Adult emerges in 8 to 11 days.

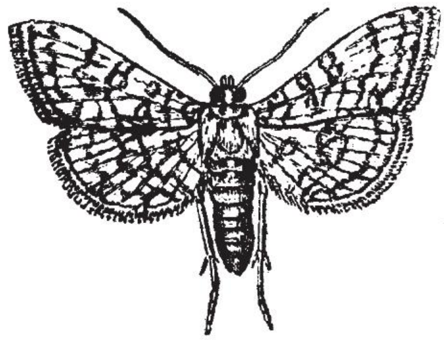
In India it infests *Amaranthus* especially *Amaranthus gangeticus, A. mangostanus, A. cruentatus, A. dubius, Trianthema monogyna, T. portulacastrum*, silverbeet, marigold, *Beta vulgaris,* mung, soybean, *Coleus parviflorus, Celosia cristata, Digera arvensis, Gomphrena celonoides,* spinach, melon, french bean, *Luffa acutangula* and various grasses.

Control: Spraying malathion 0.05% is suggested for controlling the pest on leafy vegetables. Spraying DDVP 0.05% or malathion 0.05% is suggested. The larvae are parasitised in nature by the braconids, *Apanteles delhiensis* and *Cardiochiles* sp. As the moths are attracted to ultra-violet light, traps fitted with this light can be made use of for collection of the moths in large numbers.

7. THE COTTON LEAF ROLLER *Syllepta derogata* (Fig. 65.24)

Distribution: The insect is found in Africa, Australia, Myanmar, Sri Lanka, China, East Siberia, India, Japan, Java, etc.

Damage: It is primarily a sporadic pest of cotton in India. The larva rolls the leaf and feeds on the green tissue in the early stage and eats up a large portion of the leaf as it grows. Severe attack results in the presence of a large number of leaf rolls and ultimately the plants become stunted.



▲ **Fig. 65.24** *Syllepta derogata adult*

Life history: The moth is medium-sized with yellowish wings having brown wavy markings. It lays pale white flat eggs singly on the undersurface of leaves and a female may lay up to 200 eggs. The incubation period is two to four days. The larva becomes full-grown in 15 to 20 days. It is 25 mm long, glistening green in colour with head and pro-thoracic shield dark. It pupates in the leaf roll itself and the adult emerges in 6 to 12 days. In

Uttar Pradesh the larvae hibernate in the soil from the end of November or beginning of December to June at which time they transform into pupae. There are four to five overlapping generations in a year in Uttar Pradesh.

Host Plants: Cotton, *Abelmoschus esculentus, Urena lobata, Althaea rosea, Abutilon indicum, Sida cordifolia, Kida calycina, Achyranthes aspera, Corchorus* sp., *Hymenodictyon excelsus, Malvastrum tricuspidatum, Malva parviflorus, Hibiscus rosasinensis*, etc.

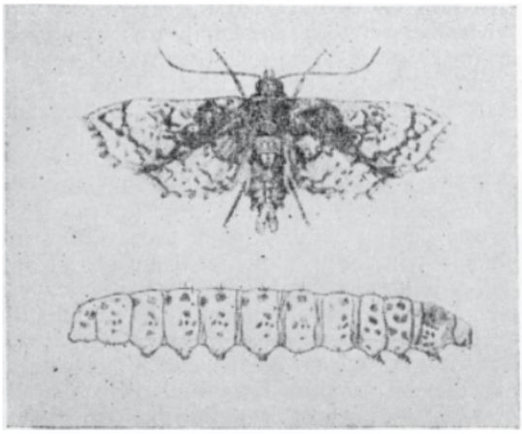
Control: The natural enemies of the insect which are parasitic on its larvae are: *Bessa remota* (Tachinidae), *Brachymeria bengalensis pulchellae* (Chalcidide), *Elasmus indicus* (Elasmidae), *Enicospilus atricornis, Goryphus nursei, Microtoridea lissonota, Xanthopimpla punctata, Neopimploides syleptae* (Ichneumonidae), *Apanteles* sp., *Bracon lefroyi, Microbracon recinicola, Phanerotoma hendecasisella* (Braconidae) and *Trichospilus pupivora* (Eulophidae). Egg is parasitised by *Trichogramma* sp. and pupa by *Xanthopimpla* sp.

Spraying chlorpyrifos 0.02% or monocrotophos 0.04% or cypermethrin 0.025% or methyl parathion 0.025% or quinalphos 0.025% or carbaryl 0.05% or acephate 0.075% is suggested.

Other Pests

Apart from the above, the following Pyraustinae are also important as pests of various crops. *Diaphania indicus* (see Fig. 65.24) is a pest causing folding of leaves in bittergourd, coccinia, pumpkin, gherkin etc.

Glyphodes caesalis and *G. bivitralis* are pests of Jack (*Artocarpus heterophyllus*). *Glyphodes stolalis* infests *Ficus* sp. and *Herpetogramma phoeopteralis* feeds inside leaf rolls of grasses and bamboo. *Herpetogramma bipunctalis* is a leaf folder on brinjal. Larvae of *Marasmia trapezalis* feed by scraping the green tissues inside leaf folds on maize, sorghum, *Pennisetum typhoideum*, grasses, etc. *Omiodes indicata* is a leaf feeder on chrysanthemum, *Lablab niger*, green gram and Bengal gram. Larvae of *Sylepta lunalis* roll the leaves of grapevine. *Omphisa anastomosalis* (Fig.65.25) is a stem borer on sweet potato. *Maruca vitrata* is a pod borer and leaf webber on a



▲ **Fig. 65.25** *Omphisa anastomosalis A-adult, B-Larva* variety of pulses like red gram (*Cajanus cajan*), lablab, cowpea, daincha (*Sesbania bispinosa*) etc. *Nausinoe neptis* and *N. geometralis* are pests of jasmine. *Syngamia abruptalis* is a pest of *Mentha arvensis* in Burma and India. It also infests *Ocimum* sp. *Syngamia latimarginalis* is a leaf folder pest of sporadic importance on the flowering plants *Barleria cristata* and *B. prionitis.*

Eye-Frequenting Moths

The adults of a few species of Pyraustinae have been reported to frequent the eyes of human beings and animals and feed on the lachrymal secretions. *Botyodes asialis* on domestic pig and elephant, *B. flavibasalis* on cow, *Filodes fulvidorsalis* (Fig. 65.26) on sambar (*Cervus unicolor*) and man, *Glyphodes stolalis* on water buffalo cattle, sambar, and domestic pig, *Pagyda salvalis* on water buffalo, pig and elephant, *Pionea aureolalis* on cattle, pig, water buffalo, elephant sambar and man, *P. flavicinctalis* on elephant and cattle and *Typsanodes lineulis* on mule, are the eye frequenting species in Thailand. In Bangladesh eyes of ox are frequented by *Psara licarsisalis, Synclera univocalis. Pionea damastesalis* frequents the eyes of pig, water buffalo, cattle, sambar, elephant, horse and mule in Thailand, cattle, goats and spotted deer (*Axis axis*) in Bangladesh, water buffalo, cattle and elephant in South India and also of man in Thailand, Sri Lanka and India.

▲ **Fig . 65.26** *Filodes fulvidorsalis feeding from the human eye (courtesy: Banziger and Buttiker, J. Medical Entomology)*

Subfamily Evergestinae

1. THE GREEN-STRIPED CRUCIFER CATERPILLAR *Evergestis forficalis*

This is a pest of importance on cabbage and cauliflower causing moderate to heavy defoliation, in Himachal Pradesh and Uttar Pradesh. The population is as high as 30-35 larvae per plant. The pest also attacks radish and Chinese *sarson*. Moths of over wintering generation emerge in April-May. The moth is yellowish to golden brown with a wing expanse of

24-27 mm, the wings having wavy grey-brown markings from costal to anal margin. A female lays in two days, 50-85 yellowish, dorso-ventrally flattened eggs overlapping in clusters of 2-42 (average 23) on the under surface of leaves. The incubation period is 6-10 days. There are four larval instars, the larval period being 14-29 days. The larva has yellowish-brown to pale head with two lateral black patches and the prothoracic shield with lateral blackened horse-shoe-shaped areas. The dorsum of both green and chocolate brown larvae has three longitudinal whitish to yellow streaks giving a striped appearance. The larva drops to the ground and pupates in the soil at a depth of 5 cm in a thin silken capsule. Prepupal period varies from 4 to 12 days. In prepupal stage it undergoes diapause from November to April. The pupal period is 10-16 days.

2. THE CRUCIFEROUS LEAF WEBBER *Crocidolomia pavonana* F.

Distribution: The insect is found in Myanmar, Sri Lanka and India.

Damage: It is a serious pest of cabbage, radish, mustard and other cruciferous plants in India. The larvae web the leaves with silken strands and feed from the lower surface of leaves completely skeletonising them. They also feed on flower buds and bore into pods.

Life history: The moth lays eggs in masses, each mass containing 40 to 100 eggs, on the lower surface of leaves, which hatch in 5 to 15 days depending on weather. The larvae become full grown in 24 to 27 days in summer and 51 days in winter. It is pale violaceous or green with red head and longitudinal red stripes on the body. Thin hairs arise on tubercles on the body. It pupates in the soil in earthen cocoon and the adult emerges in 14 to 40 days. In summer the life cycle is about a month. In India it is known to feed on cabbage, radish, mustard, turnip, *Lepidium sativum* and *Gynandropsis pentaphylla.*

Subfamily Glaphyriinae

THE CABBAGE BORER *Hellula undalis*

Distribution: The insect has a world-wide distribution and is a pest of cruciferous crops.

Damage: The larva in its first two instars mines the leaf along the side of vein and reduces it to a white papery structure with excreta in it. Thereafter, as the larva grows, it nibbles at the chlorophyll of the leaf and later feeds on the cauliflower or cabbage heads, leaf petiole, stem, etc. In cases of severe attack almost all the plants may be found infested. The plants lose their vigour and bear deformed heads.

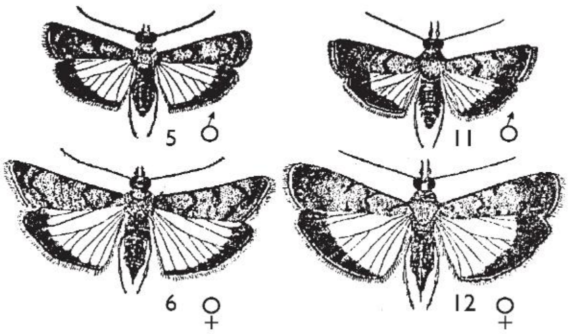
Life history: The moth is greyish brown, forewings having wavy grey markings and hindwings pale dusky. It lays the pinkish oval eggs either singly or in groups, each group having up to 20 eggs, mostly on the undersurface of leaves, or occasionally on shoots and tender stems. Incubation period is two to three days. It passes through four and rarely five larval instars and becomes fully grown in 7 to 12 days. The full-grown larva is creamy yellow with a pinkish tinge and five distinct pinkish brown longitudinal stripes, one middorsal and two dorso-lateral on either side. The head and prothoracic shield are black and creamy white with dark spots respectively, and the body has sparsely distributed hairs arising on minute tubercles. It measures 14 to 16 mm in length. It pupates generally in the burrow itself on the plant. The adult emerges in six to ten days. Total life cycle is 15 to 25 days, average being 19 days. It feeds on cabbage, cauliflower, radish, knolkhol, beet and *Gynandropsis pentaphylla.*

Control: In nature larva is parasitised by a braconid, *Habrobracon hebetor* up to 33.9 %. Spraying malathion 0.05 % may be useful.

Subfamily Noordinae

1. THE MORINGA BUDWORM *Noorda moringae* (Fig. 65.27)

It is one of the important pests of *Moringa oleifera* in India. The larvae feed on young flower buds, which results in shedding. Infestation goes up to 78 % in the affected plants. The infestation is generally lower during October-December and reaches the peak in June.



▲ **Fig. 65.27** *Left: Noorda moringae; Right: Noorda blitealis*

Life history: The adult is small and dark brown. It lays oval, creamy white, slightly sculptured eggs in clusters and occasionally singly on the buds. A female may lay up to 250 eggs. Egg stage lasts for three to four days. The larva bores into the bud and first feeds on the anthers and then on the other internal parts leaving the outermost petals intact. Only one larva is seen in a bud. Larval period is 8 to 16 days. Full-grown larva measures

11 to 14 mm long, is dirty brown with a prominent mid-dorsal stripe, head and pro-thoracic shield being black. Infested buds drop down and the larvae pupate in the soil in a cocoon of silk covered with soil particles. Adult emerges in six to ten days. Total life cycle is 10 to 28 days.

Its natural enemies include the following larval parasites: *Pristomerus* sp. (Ichneumonidae), *Bracon brevicornis*, *Chelonus* sp. (Braconidae), *Elasmus hyblaeae, Perilampus* sp. and *Systasis* sp. (Chalcidoidea). Raking up the soil around the trees may destroy the cocoons of the insect.

2. THE MORINGA LEAF CATERPILLAR *Noorda blitealis* (Fig. 65.27)

Unlike *N. moringae,* which is a pest of the flower buds of moringa, larvae of *N. blitealis* feed on the leaves of moringa while hanging from the undersurface of leaflets in a thin silken web. Trees soon appear with dried up papery structures on petioles. As the leaves are also used as vegetables its damage to the trees is of great significance. The attack is severe during March-April and December-January.

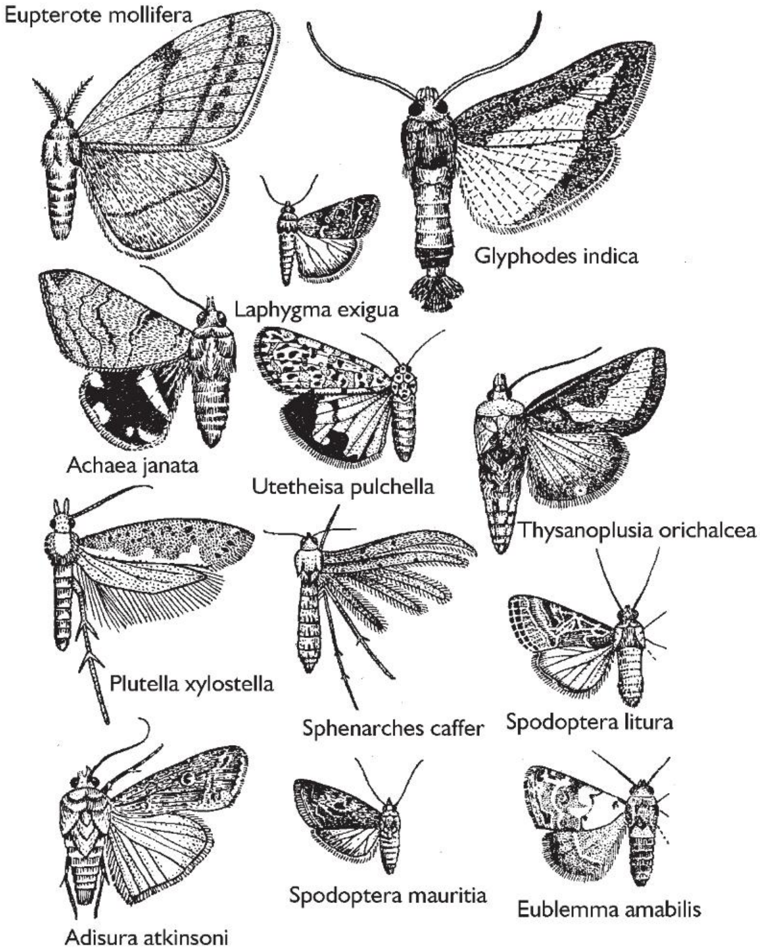
Life history: The moth is dark brown and the black pattern on forewings broader and wavy. Black shading on hindwings is broader. It lays creamy white oval eggs in clusters of 34 to 96 on tender portions of leaves. A female lays up to 232 eggs. Incubation period is three days. Grown up larva measures 19 to 20 mm long with a pale brown head. Prothoracic shield is wanting. Larval period is 7 to 15 days. It pupates in the soil and the adult emerges in six to nine days. Total life cycle is 16 to 26 days.

Control: Spraying malathion 0.1 % or dichlorvos 0.1 % may be useful in controlling the pest.

Superfamily PTEROPHOROIDEA

Family Pterophoridae (plume moths)

These are small lightly built moths with the extremely elongate forewings being longitudinally cleft into two, three or four divisions and the hindwings into three. In rare cases members of *Agdistis* and two other genera possess undivided wings. Maxillary palpi are absent. Legs are long and slender with tibial spurs. The larvae feed on leaves and flowers and rarely inside stems. Among the Indian species, *Exelastis atomosa* is a pest on pulses and *Sphenarches caffer* (Fig. 65.28) on pulses and gourds. *Diacrotricha fasciola* infests *Averrhoa carambola* and *A. bilimbi. Oxyptilus luctucae* attacks lettuce and *O. regulus* is a berry borer on grapevine. *Pterophorus lienigianus* infests brinjal. Larva of *Trichoptilus* sp.nr. *congrualis* infests



▲ **Fig. 65.28** *Some moths of economic importance*

flower buds of *Barleria cristata* and *B. prionitis*. *Lantanophaga pusillidactyla* feeds in the flower heads of *Lantana camara, L. indica, L. wightiana* and *Lippia geminata*. Other Indian species are *Buckleria* sp., *Trichoptilus* sp., *Deuterocopus* sp., *Platyptilia* sp., *Stenoptilia zophodactyla, Steganodactyla concursa*, etc.

1. THE REDGRAM PLUME MOTH *Exelastis atomosa*

It is an important pest of *Cajanus cajan* (redgram) and *Lablab niger* and larva feeds on flower buds, flowers and developing seeds inside pods.

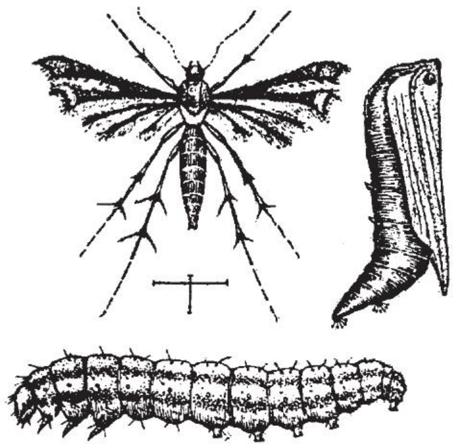
The moth is delicate, dry-grass coloured and possesses deeply fissured wings. It lays greenish oval eggs singly on flower buds, tender pods and rarely on leaves. A female may lay as many as 94 eggs. Incubation period is four days. The larva feeds on the seeds from remaining outside the pod. It is green, brown or greenish brown with hairs radiating from tubercles on body. Larval period ranges from two to four weeks. It pupates on the outside of pod itself attached to it. The adults emerge in four to eight days.

Dusting carbaryl 10% or methyl parathion 2% or quinalphos 1.5% thrice at fortnightly intervals commencing from the flowering stage affords protection.

2. THE GRAPE PLUME MOTH *Oxyptilus regulus*

The insect (Fig. 65.29) is distributed in Sri Lanka, Australia and India. In India (Karnataka State) the larva bores into the ripening berries of the grape bunches and inflicts considerable loss. A larva may damage a number of berries.

The moth is delicate and very dark in colour and lays oval, smooth, shining white eggs singly at night on the berries, round the fruit stalks and on the peduncle. The incubation period is four to five days. The full-grown larva measures 8 to 9 mm, is deep chocolate brown in colour with three dorsal longitudinal, pale yellow interrupted stripes and a broad lateral one on each side. The head is pale yellow and pro-thoracic shield pale with dark margin anteriorly. Larval stage lasts for 12 to 13 days. The larva pupates on the peduncle or on the surface of healthy berries and on weeds of dry leaves if it falls to the ground along with the damaged berry. The adult emerges in ten days. The life cycle occupies 26 to 28 days.



▲ **Fig. 65.29** *Oxyptilus regulus Top: Adult, Bottom: Larva, Right Top: pupa. (T.V. Subramanian, Bull. entomological Res., 30:471–473, 1940)*

Superfamily PAPILIONOIDEA

This includes the butterflies, which have clubbed or dilated antennae. A frenulum is absent and a well-developed humeral lobe is present on the hindwing. Rarely a few others possess clubbed antennae but they are readily distinguished from the members of

Papilionoidea by the presence of a frenulum. The following families, viz. Nymphalidae, Danaidae, Satyridae, Heliconiidae, Libytheidae, Lycaenidae, Pieridae, Riodinidae and Papilionidae are included under this superfamily.

Family Danaidae (Euploeiinae, Limnadidae)

Butterflies of this family have scaleless antennae often ending in antennal club only slightly pronounced. A corrugate knob is present at the terminal end of the very small forelegs. The larvae are strikingly coloured with black and yellow, green or red and have two to four pairs of fleshy processes variously distributed on the mesothorax and on one or more of the abdominal segments. The pupa is suspended by its caudal extremity. Disagreeable odour, taste, and leathery consistency of the body of adults afford them protection from natural enemies. A pair of protrusible brushes of hair at the abdominal end and a scent producing pouch on the hindwing are present in male. This family comprises the species of common genera such as *Danais, Euploea, Amauris*, etc. The "plain tiger" *Danais chrysippus* is a very common butterfly found in India, the larvae of which feed on the leaves of *Calotropis gigantea, Eruca sativa*, etc. *Danais plexippus* is another common species, which breeds on *Asclepias, Ceropegia, Raphistemma*, etc. *Euploea core*, known as "Indian crow," feeds on *Nerium odorum, Ficus religosa* and *F. glomerata.*

Family Satyridae (Agapetidae)

Butterflies of this family are known as "meadow browns," "heaths," "graylings" and "marbled whites." They are small to medium sized, largely shade-loving, dusky butterflies with eye-like or annual spots on wings. Certain veins at the base of forewings are greatly swollen except in *Melanitis.* The fusiform larva is green, yellowish or brown with two horn-like processes on the head, a constricted prothorax, body having small papillae bearing short secondary setae, a pair of short backwardly pointed processes from the bifurcate subanal plate and longitudinal lines on the body. The chrysalis is suspended by its caudal extremity. *Melanitis leda ismene* is the rice horned caterpillar. Wet and dry season forms as well as numerous local races occur in this species. *Orsotrioena meda* infests rice. *Mycalesis perseus*, *M. blasius, Ypthima hubneri, Lethe europa*, etc. are some common species.

THE RICE LEAF BUTTERFLY OR HORNED CATERPILLAR *Melanitis leda ismene*

The insect is found in Australia, South-east Asia, South India and West Africa. It feeds on rice and grasses, and is of minor importance. The butterfly is dark brown with large wings having a black and yellow eye spot one on each of the forewings and six ocellar spots on hindwings.

The female lays spherical white eggs on rice leaves and the incubation period is four days. The larva is green, slightly flattened with a rough body surface and two brown horn-like processes on the head and a pair of two slender processes at the anal end. It feeds on leaf blade and becomes full grown in 23 days. The dark green chrysalis hangs from the leaf and is attached to the leaf blade by its anal extremity. The adult emerges in ten days.

Family Nymphalidae (brush footed butterflies)

This is a large family with brightly coloured butterflies flying in the sunshine. They have considerably reduced forelegs in both sexes, which are functionless and generally folded on the thorax. The short tibiae are covered with long hairs and hence the name "brush-footed" butterflies. The tarsi of forelegs are unjointed in males and four- or five-segmented in females. The larvae are characteristic in possessing numerous spinous processes and the last abdominal segment bears a pair of backwardly directed processes. The chrysalis often has prominent tubercles in rows on the abdomen and in some a pointed projection on either side of the head. It is usually suspended by the cremaster.

The most remarkable of the members of this family is the Indo-Malayan *Kallima,* which includes the "leaf butterflies". The under surface of the wings of these butterflies resemble dry leaves when the insect is at rest whereas the upper surface of the wings is beautifully coloured. *Kallima philarchus* occurs in Sri Lanka and South India and breeds on *Strobilanthes. Vanessa cardui,* the "painted lady", is a very beautiful butterfly and has a world-wide distribution. The other Indian species is *Vanessa indica. Charaxes fabius* is a large butterfly common in the plains. The beautiful green larva of *Euthalia garuda* feeds on mango leaves in India. *Ariadne merione merione* is a specific pest on castor. *Junonia hierta, J. orithya* and *J. lemonias* are pests of the flowering shrub *Barleria cristata* in South India. *Junonia orithya* also attacks sweet potato. *Junonia almana* is a minor pest of rice. Females of *Hypolimnas missipus* mimic *Danais chrysippus* whereas the black males have two white spots on each of the forewings and one large patch on each of the hindwings. *H. missipus* breeds on *Portulaca oleracea.* Other common species are *Neptis eurynome, Cyrestis thyodamus* and *Rahinda hordonia.*

Family Riodinidae (Erycinidae, Nemeobiidae)

These insects are distributed in neo-tropical region, United States and the eastern hemisphere. The butterflies are small with short broad forewings. In the male the forelegs are brush-like with single-segmented tarsi having no claws and not useful in walking. In the female the forelegs are perfect though they are slightly smaller than the remaining pairs. The family has two subfamilies, viz. Nemeobiinae and Libytheinae. Nemeobiinae includes *Nemeobius lucina*, the European form and the Indian *Dodonia* sp. Libytheinae includes the genus *Libythea.*

Family Lycaenidae (blues, coppers, hair streaks)

Small to moderate-sized butterflies with upper surface of wings being metallic blue or coppery, dark brown or orange and undersurface more sombre with delicate streakings or dark-centered eye-spots. Tail-like delicate prolongations are seen on hindwings. Each eye is surrounded by a rim of white scales and the antenna ringed with white. Legs are normal excepting the forelegs of males which may possess more or less shortened tarsi, and may be wanting in one or both claws. The colouration in both sexes may often show great differences. Lycaenid larvae are characteristically onisciform with both ends tapering and the enlarged sides concealing the legs. They have numerous secondary setae on their body and in some the body may be smooth. The pupa is stout and relatively short with rounded anterior portion. The abdominal segments show little or no movement. The pupa is attached to the surface by its anal end and is held by a central girth of silk. In rare cases the pupa is subterranean.

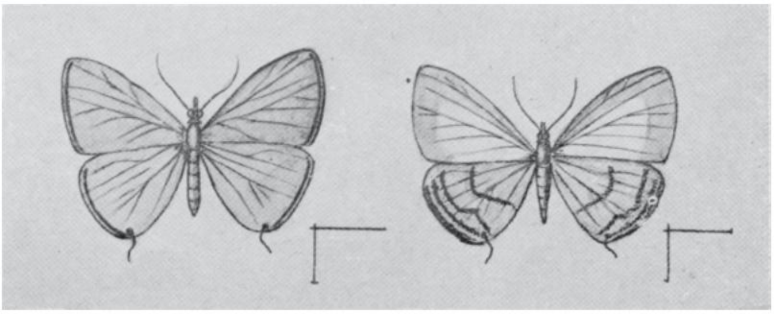
Lycaenid larvae feed variously. Certain species are carnivorous. In China *Gerydus chinensis* preys upon aphid. The woolly aphis is fed upon by the American *Feniseca tarquinius.* In its last larval instar *Maculinea arion* frequents nests of the ant, *Myrmica* and preys upon ant larvae. The nests of the ant *Oecophylla smaragdina* is frequented by the Indo-Australian lycaenid *Liphyra brassolis* and similarly in West Africa by *Euliphyra mirifica.* In Sri Lanka and India, larvae of *Spalgius epius* have been noticed to be predaceous on a number of coccids. The larvae of some species exude a fluid from a dorsal gland situated on the seventh abdominal segment and ants attend on them. It is interesting that on a single occasion in Thailand an adult of *Lampides boeticus* has been noticed to frequent the eye of a domestic pig.

Among the phytophagous forms, a few are pests of crops. Larvae of *Lampides boeticus* and *Catochrysops cnejus* feed on flower buds and seeds inside the pods of pulses like lablab, cowpea, pigeon pea, etc. *Deudorix isocrates* and *Rapala varuna* are fruit borers on guava. Larva of *Tarucus theophrastus* feeds on leaves and buds of *Zizyphus jujuba* and that of *Lampides elpis* on flowers and fruits of cardamom. Leaves of *Bryophyllum calycinum* are mined by *Talicada nyseus.* Top shoots of orange are damaged by *Chilades laius. Pongamia glabra* is attacked by *Curetis thetis.* The other Indian species are: *Zizera lysimon*, *Chilades trochiluspútli*, *Lycaenesthes emolus*, *Catochrysops pandava*, etc.

1. THE BLUE BUTTERFLY Catochrysops *strabo*

This species is distributed in India, Sri Lanka, Myanmar, Java, Formosa and Australia. It is a pest of *Cajanus cajan* (pigeon pea) in India. The larvae feed on the floral buds by making a hole in the corolla and entering partly feeds on the inner contents. When the pod is attacked the larva makes a separate hole at each time for feeding on each seed in the pod.

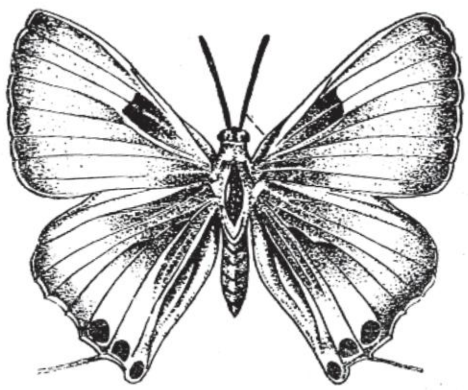
The disc shaped round and flat whitish eggs with bluish tinge are laid on unopened buds and sometimes on pedicels. The incubation period is four to five days. The full-grown larva is dark green with black shining head and pupates on the leaf secured by a girdle of silken threads around the body at first abdominal segment. The pupa is dirty brown with black dots on the dorsal surface. Dorsal side of both the wings in males is pale violet blue with silvery reflection. Hind wing has a caudal appendage with an ocellate spot of deep black colour. The ventral side of both the wings are whitish grey with white wavy bands. In the female the dorsal side of fore wings possess a broad brown border and hind wings possess a series of ocellate spots near the margin.



▲ **Fig. 65.30** *Catochrysops strabo. Left— Male; Right— Female (Tale. Y.M. and Rane. A.E., Indian J. entomol.,* **34;** *347–348, 1972)*

2. THE POMEGRANATE FRUIT BORER *Deudorix isocrates*

The butterfly is bluish-brown with an orange patch on the forewing and spots on the hindwing. It lays shining white eggs singly on the flowers or on the surface of tender fruits. The larva bores into the fruit and feeds on the seeds. Often the hole can be seen plugged by the anal segment of the larva. The larva is dirty brown, stoutly-built, covered with a few short hairs and measures about 16 to 20 mm long. It pupates inside the fruit or on the stalk. Life cycle is about one to two months.



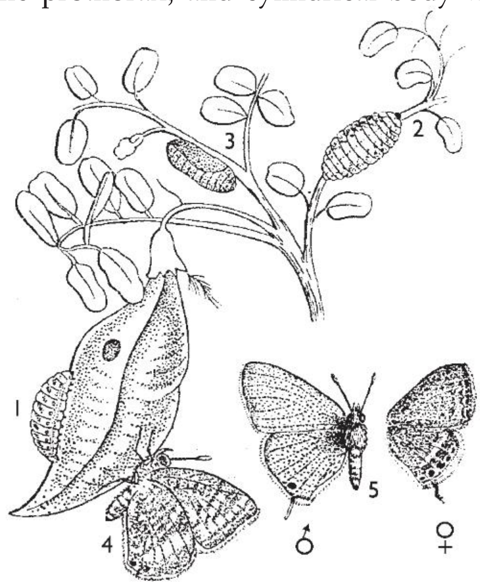
▲ **Fig. 65.31** *Pomegranate fruit borer, Deudorix isocrates*

It also attacks fruits of guava, tamarind, loquat, soapnut tree, wood apple, etc. Screening the fruits with polythene or paper bags may prevent attack. Five spray applications of fenvalerate 0.1% or fluvalinate 0.01% or carbaryl 0.2% or triazophos 0.05% at intervals of three weeks commencing at initiation of fruit setting is suggested.

3. THE PIGEON PEA BUTTERFLY *Lampides boeticus* Linn. (Fig. 65.32)

It is one of the important pests of pigeon pea in the country. The larva bores into the pods and also feeds on flower buds and flowers.

The adult moth measures 10-12 mm long and 28-32 mm across the wings. The wings are violet metallic blue to dusky blue. The tail in each hindwing is black, tipped with white. The longevity of adult is two to six days. Copulation takes place during day time. The female lays 32-120 eggs in two to five days, singly or in groups of two to three on the flower buds, green pods and to a lesser extent on shoots and leaves. The egg is greenish-white, round with a slight depression at the top, beautifully sculptured with white net work and measures 0.35 mm in diameter. The incubation period is four to seven days and the larva passes through five instars. Newly hatched larva is 0.97 mm long, yellowish-green with black head and a dark brown patch on the prothorax, and cylindrical body with scattered hairs. The larva starts boring into the flower buds or pods just three to five hours after hatching and feeds inside. The full-grown larva is variously coloured, yellowish-green to yellowish-red or sometimes light purple with brownish mid-dorsal and yellowish lateral lines; ventrally light green; head is dark brown and body with minute setae. The seventh abdominal segment is provided with two groups of setae arranged in circles on either side of the mid-dorsal line. Larva looks like a slug with head at rest concealed under the pro-thorax and measures 3-4 mm long. Larval period lasts for 9-27 days depending on weather conditions. It pupates on the leaves, twigs or on pods. The pupa is greyish pink to reddish-brown, whole surface marked with irregular black markings, and measures 8-11 mm long. The pupal period is 7-19 days. The total life



▲ **Fig. 65.32** *Lampides boeticus. 1 to 3: Larvae and 45: adults (T.B. Fletcher, 1914)* cycle period ranges from 20 to 53 days. The pest is active from November to March and passes through two to three generations. In Uttar Pradesh, it is not prevalent during April to November and it is reported to be a regular migrant.

It has been reported to infest *Butea frondosa, Cajanus cajan, Cicer arietinum, Crotalaria calycina, C. juncea, Lablab niger, Medicago sative, Rumex maritimus, Sesbania sesban, Vigna catjang, V. mungo, V. radiata,* etc.

4. THE BRYOPHYLLUM LYCAENID *Talicada nyseus*

The butterfly known as the "Red Pieroot" is known from India, Myanmar, Assam and Sri Lanka. The insect is a pest of the succulent rockery plants *Bryophyllum calycinum* and *Kalanchoe kirkii.* Though it occurs in South India throughout the year it is abundant during March-May and September-December. The larva mines into the thick fleshy leaf and feeds on the parenchymatous tissue. The leaf becomes pale with the blotched mine containing the excreta of the larva. The leaves dry up in due course and fall down, leaving the main stem and petioles. The adult is violet brown with deep black forewings, and hindwings having a conspicuous orange-red band on its lower third. Wing expanse is 28 to 42 mm. Mating takes place end to end. A female lays a maximum of 96 eggs in two days. The whitish-round egg is sculptured like a sea urchin without spines. The eggs are laid singly on the stem, petiole, leaf surface, etc. The eggs hatch in three days. The larva becomes full-grown in about 21 days and measures 10 to 12 mm. It is pale olive yellow in colour with body covered with thin hairs. Head is small and concealed and the anal segment flattened. The larva leaves the mined leaf only at the time of pupation. It pupates on the leaf itself. The adult butterfly emerges in nine days.

Family Pieridae (whites)

These are medium-sized butterflies, white or orange or yellow coloured with black markings. Legs are alike and normal in both sexes. The larvae are devoid of osmeteria, fleshy filaments, cephalic and anal processes and their body segments are divided into annulets. Numerous secondary setae are present on the body of the larvae. The crochets of prolegs are bi- or tri-ordinal arranged in a mesoseries. The pupa is attached to the host plant by its anal end and a central band of silken thread suspends it in an upright position. The pupa is characteristic in having a single median projection or spine, and also in that hindwings are not visible ventrally. Butterfly migration occurs in certain species such as *Appias* and *Catopsilia.* In North India butterflies like *Pieris brassicae, P. boeticus* and *Eurema blanda silhetana* move up to cooler regions in March-April with the onset of hot weather and down again with the commencement of cool weather in September-November.

The larvae of Pieridae feed on plants belonging to the natural families Cruciferae, Capparidaceae and Leguminosae. *Pieris rapae* is one of the important pests of cruciferous vegetables in Europe and North America. In India *Pieris brassicae, P. rapae, P. napi* and *P. canidia* infest cruciferous crops. *Catopsilia pyranthe, Colias hyale, Eurema hecabe* var. *contubernalis*, etc. infest a number of papilionaceous plants. *Eurema blanda silhetana* is a pest of shade trees in tea plantations in North-east India.

THE SHADE TREE PIERID *Eurema blanda silhetana*

The butterfly is found in India, Myanmar and Sri Lanka. It is one of the important pests of shade trees in tea plantations. The early instar larvae nibble the outer epidermis of leaflets and as they grow eat away the leaflets. Seedlings in the nursery are defoliated. Young plants and occasionally big trees may be stripped off their leaves.

The butterfly breeds on *Caesalpinia bonducella, Acrocarpus fraxinifolius, Albizzia lebbeck, A. chinensis, A. falcata, A. odoratissima, Cassia nodosa, Glyricidia maculata, Poinciana regia, Sesbania bispinosa, Wagatea spicata* and *Xylia dolabriformis* in India.

The butterfly is active during cold weather and early spring. The eggs are laid in upright position in clusters on the undersurface of tender leaflets and occasionally on the rachis, axils and unopened leaf buds. The egg is white and spindle shaped and in each cluster there may be 28 to 137 eggs, the average being 65 eggs. The incubation period is 12 to 14 days. The larva becomes full-grown in 22 to 26 days in December and 11 to 14 days in March. It measures 26 to 30 mm long, green with a pale lateral stripe on the body and with a black head. Body segments are annulate. Numerous black tubercles are seen on the body. The larvae pupate in conspicuous clusters on the rachis and midribs of leaves and are suspended in upright position. The pupa is olive green but changes to brown and then black. Its head is prolonged anteriorly into a snout-like process. The butterfly emerges in 11 to 14 days in December and six to seven days in March.

The larva is parasitised by *Euplectrus* sp. and an ichneumonid *Charops obtusus*, and the pupa by a chalcid *Brachymeria megaspila*.

In the nursery and on young plants the eggs, larvae and pupae may be hand picked easily and destroyed. Spraying of endosulfan 0.07% or cypermethrin 0.025% is suggested.

Family Papilionidae (swallow-tails)

These are mostly tropical species. Most of them are large and conspicuously coloured and possesses a tail-like prolongation on hindwings. The wings are generally iridescent black with shades of green, red, yellow or blue. Body of larva is smooth or with a series of fleshy dorsal tubercles or occasionally with a raised prominence on the fourth segment. Setae are absent on the body, exception being *Parnassius,* which has secondary setae and verrucae.

On the prothorax is present an eversible osmeterium. The pupa is characteristic in having two lateral cephalic projections and the hindwings being visible ventrally. It is suspended by its anal extremity in an upright position and is held by a median silken girdle. A cephalic as well as an anal attachment is present in *Thais.* In *Parnassius* the pupa is found in a silken web among leaves and is not suspended. Distinct differences exist in form, colour, and often in habits among many species. Polymorphism is common in females of numerous species and in others it may be evident in both sexes. In the Oriental *Papilio memnon* three distinct forms occur in each sex and two female forms are tailless. Three distinct seasonal forms are observed in the North American *Iphiclides ajax.* Different races or subspecies, each having one to five forms in the female are known in the African *Papilio dardanus.* Anal pouches develop in the females during copulation in *Parnassius.*

Papilio demoleus is the lemon butterfly, which is distributed throughout India and is a pest on citrus. Other common Indian species are: *Papilio polytes, P. machaon, P. helenus, P. memnon, P. pammon, P. polymnester, Zetides agamemnon* and *Tros aristolochiae.*

THE LEMON BUTTERFLY *Papilio demoleus*

The insect is distributed in Africa and Asia. It is a pest of regular occurrence on citrus in India. The larvae feed on leaves and defoliate the trees.

The butterfly is beautiful, the wings having black and yellow markings, and on the hindwings towards the inner margin a brick red oval patch is present. It lays 75 to 120 shiny, greyish-yellow eggs in two to five days on the underside of tender leaves. The incubation period is three to eight days. There are five larval instars. Early instar larva is dark with white patches resembling the dropping of birds. When grown up it turns deep green in colour, stout and cylindrical in shape, and measures 40 mm long with a hump- like raised portion anteriorly. The larval stage lasts for 11 to 40 days. It pupates in a naked chrysalis attached to the plant by two fine strands of silk in the form of a girdle. The adult emerges in a week in summer and in 12 to 20 weeks in winter. Normally its life cycle occupies 18 to 40 days and depending on temperature extends up to 145 days.

Apart from *Citrus* sp. it also attacks *Murraya koenigii, Aegle marmelos, Psoralea corylifolia, Feronia elephantum* and other rutaceous plants.

The larvae are attacked by a yellow wasp *Polistes herebreus* and the preying mantis *Crebrator gemmatus.* The larval parasite is *Charops* sp. (Ichneumonidae), and *Brachymeria* sp. is parasitic on its pupa.

Hand picking and destruction of the larvae wherever feasible may be done. Spraying methyl parathion 0.025% or cypermethrin 0.025% or fenvalerate 0.02% or monocrotophos 0.04% or quinalphos 0.025 % is suggested as preventive measure.

Superfamily HESPERIOIDEA

Adults are without maxillary palpi but with more or less rough-haired labial palpi. Antennae have apically dilated club, which often ends in a hook, which is characteristic of the members of this superfamily. Frenulum is wanting in hindwing excepting in the male of *Euschemon.* This superfamily includes a single family, Hesperiidae.

Family Hesperiidae (skippers)

The members of this family are known as "skippers" in view of their erratic and darting movements during flight. These are widely distributed insects but most of them are tropical. The antennae are widely separated at their bases and each antenna is apically prolonged beyond the club into a hook or a small recurved point. The larvae are moderately stout, with the body tapering at both ends. The body may be covered with small secondary setae or they may be absent dorsally. The crochets are triordinal arranged in a circle. The larva is very characteristic in having a relatively big head attached to a neck-like or constricted "collar." Larvae web the leaves or form galleries with silken threads and remain inside them; those belonging to the subfamily Megathyminae are borers. The pupa is found enclosed in the leaf in a slight cocoon or may be naked. It is attached by the anal end and also by a median band of silk.

Among the common skipper butterflies found in India, *Parata alexis* on *Pongamia glabra, Gangara thyrsis* and *Suastus gremius* on coconut, *Udaspes folus* on turmeric, *Telicota augias* on sugarcane and rice, *Pelopidas mathias mathias, Borbo cinnara, Parnara guttatus guttatus* (Fig. 65.33) and *Ampittia dioscorides* on rice are of some importance in agriculture.

▲ **Fig. 65.33** *Parnara guttatus guttatus–Larva in rice leaf (Courtesy: Mitsui Toatsu, Japan)*

THE RICE SKIPPER *Pelopidas mathias mathias*

The insect is found in India, Pakistan, South-east Asia, China, Egypt, Rwanda, Burundi and West Africa.

The larva longitudinally folds the leaves making the edges stick together by means of silken threads and feeds on the green matter from inside. Sometimes a few leaves of tillers are closely webbed together and the larva feeds on the leaves resulting in stunting of hills in rice crop.

The butterfly lays 30 to 95 spherical, flat based, creamy white, eggs singly on leaves in two or four days. The incubation period is three to six days. The full-grown larva measures 35 mm long, pale green with yellowish-white lines across the back and laterally a whitish line on either side. The pale green head has two vertical red streaks. The larval stage lasts for 13 to 39 days depending on climatic conditions. The pale green pupa has white longitudinal lines on it and is attached to the leaf blade by its caudal extremity supported by a silk girdle. The adult emerges in about 7 to 30 days. The total lifecycle may be about six weeks. The butterfly is brown with whitish specks on each of the forewings. The insect passes through four overlapping generations during August-November and thereafter the larvae hibernate and emerge as adults in spring.

Apart from rice it also breeds on sugarcane, sorghum, maize, *Eleusine coracana, Paspalum scrobiculatum, Cynodon dactylon*, grasses, etc. In India, the larvae are parasitised by the Ichneumonids *Xanthopimpla emaculata* and *Ischnojoppa luteator*, *Clinocentrus* sp. (Braconidae) and *Eupteromalus parnarae* (Pteromalidae). The pentatomid *Andrallus spinidens* is predaceous on the larva.

Superfamily GEOMETROIDEA

Adults are with vestigial or atrophied maxillary palpi and tympanal organs in abdomen. This super family includes the following families: Axiidae, Drepanidae, Thyatiridae (Cymatophoridae), Geometridae, Uraniidae, Epiplemidae and Sematuridae.

Family Axiidae

Members of this family possess the tympanal organs on the seventh abdominal segment whereas in the others they are seen on the first or second abdominal segment. It includes a few Mediterranean species.

Family Drepanidae (hook tips)

These are found in the Indo-Malaysian region of the Orient, and include the genera *Drepana, Cilix*, etc.

Family Thyatiridae (Cymatophoridae)

They resemble Noctuidae and are mainly seen in the northern hemisphere. Some common species are *Habrosyne derasa* and *Thyatira batis* in the British Isles.

Family Uraniidae

Mainly tropical species which are brightly coloured. Species belonging to the genera *Chrysiridia, Nyctalaemon* and *Urania* resemble papilionid butterflies and the others resemble geometrid moths.

Family Epiplemidae

A small group of inconspicuous species found in all continents. The moths at rest resemble spiders.

Family Geometridae (true loopers, carpets, waves, pugs, etc.)

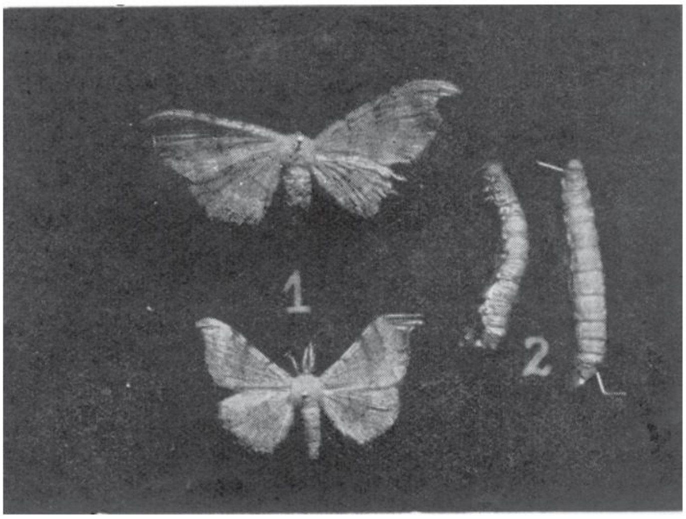
This is a very large family, the members of which have a slender body with relatively large wings. The moths are not strong fliers and often keep the wings horizontally at rest. Generally the moths have proboscis and frenulum and in a few cases either the one or the other may be absent. Females of some genera possess degenerate wings. *Alsophila, Apocheima, Eranius, Operoptera* and its allies are apterous. The larvae are generally elongate and slender. They possess prolegs on the sixth and tenth abdominal segments. Locomotion is achieved by drawing the posterior segment close to the thorax, the body thus forming a loop, and then extending forward. The looping action is repeated in this way. In some cases the prolegs are developed on segments other than those usually carrying them. The larvae at rest often resemble dried up twigs or thicker veins of leaves. The pupa may be subterranean or may be found in a slight cocoon among webbed leaves.

A few are pests of crops in India. *Biston suppressaria* on tea, *Thalassodes quadraria* on mango and *Polyalthia longifolia*, *T. veraria* on mango, rose, litchi, etc., *Semiothisa pervolgata* on the green manure crop, *Sesbania bispinosa, Hyposidra successaria* on *Sesbania speciosa* and *H. talaca* on castor are of some importance.

In their adult stage a few species of geometrid moths have been reported to frequent the eyes of man and animals for their lachrymal secretion. The human eyes are frequented by *Hypochrosia hyadaria, H. flavifusata* and *H. pyrrhularia* in Thailand. The following moths have been observed to frequent the eyes of animals in Thailand: *H. flavifusata* of cattle, water buffalo and pig, *H. korndorfferi* of cattle, water buffalo and sambar, *Peratophyga* sp.nr. *tonseae* of pig, *Semiothisa fasciata* and *S. myandaria* of water buffalo, cattle and sambar, *Scopula attentata* and *Pingasa chloracrenaria* of elephant, cattle and water buffalo, and *Somatina anthophilata* of water buffalo, pig, cattle and sambar. In Bangladesh *Antitrygodes cuneilinea* frequents the eyes of ox and cattle. *Semiothisa inaequilinea* frequents the eyes of sheep in Africa.

1. THE SESBANIA LOOPER *Hyposidra successaria* (Fig. 65.34)

It is distributed in India, Myanmar, Sri Lanka and Java. The early instar larvae scrape the green matter on tender leaves and at later stages cut the edges and feed on entire leaflets leaving only the thicker veins and midribs. When they occur in large numbers they feed voraciously on the foliage and reduce them to mere stalks.



▲ **Fig. 65.34** *Hyposidra successaria.1. Adults, 2. larvae (S. Venugopal, Indian J. entomol.* ***20****: 283–290, 1958)*

Host Plants: Rose, castor, sugarcane, cabbage, *Euphorbia hirta, Sesbania bispinosa, S. grandiflora, S. speciosa, Eugenia* sp., mango, *Zinnia,* etc.

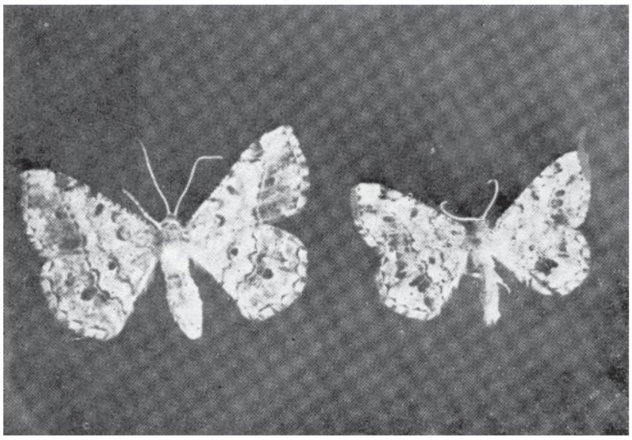
Life history: The moths copulate a day after emergence. The female lays 250-300 eggs in batches. The eggs are laid in five to six days on the surface of leaves. The egg is oval, greenish and measures 0.8 mm in diameter. The incubation period is four to five days. The larva passes through five instars. The full-grown looper is 3.5 cm long, pinkish, dark brown or brick red with a white spotted transverse band, which persists with brownish or brick red patches at the sides. Paired brown dots are prominent dorsally on second and fifth abdominal segments. The head is small, shiny, smooth and faintly marked with mottlings and black ocelli. Legs are dark brown. The larval period lasts from 18-20 days. Pupation takes place in the midst of fallen leaves. The pupa is dark brown and the pupal period ranges from eight to nine days. The moth is fairly big having a wing expanse of 6 cm in female and 4 cm in male; the wings showing varying shades of chocolate brown and brick red colour. The antennae of male are pectinate. The total life cycle ranges from 30 to 32 days. There are four broods in a year and it is active during June to November.

2. THE POINCIANA LOOPER *Pericyma cruegeri*

This species is distributed in Australia. Borneo, Philippines, Papua and New Guinea, Thailand, Tonkin, Kauai Island of Hawaii and Rota. This was introduced in Guam in 1971 and since then has become a serious pest of royal poinciana *Poinciana regia* and yellow poinciana *Peltophorum pterocarpum*. It has been reported to attack *Desmanthus virgatus*. In Papua it has been noticed to infest *Cassia fistula, Leucanea leucocephala, D. regia* and *P. pterocarpum*. The larvae cause complete defoliation of trees. The dark grey moths measure 3.5-4.0 cm across wings. The moths oviposit during the night and the eggs are laid singly and sometimes in groups of two to three eggs on the leaflets. The egg is semispherical, yellowish-green to bluish-green with longitudinal lines. The incubation period is two to three days. There are five larval instars. The fully-grown larva is about 5 cm long with a greenish head. The body is green with five white dorsal and two black lateral longitudinal lines. Above each spiracle is a black patch and below a white patch. The colour of larvae varies. In some, the head is yellowish-green and the five white longitudinal lines merge to form a white band on the dorsal side. Laterally, a prominent black band covering the spiracles is present. The prepupal stage lasts for two days, when the larva constructs a globular cocoon by binding the leaflets and rachises with silken threads. The chocolate coloured pupa is covered with a white waxy coating. The pupal period varies from 9-12 days. The total life cycle takes about 40 days. The pupae are parasitised by *Exorista civiloides* (Tachinidae). The predators noticed are *Hierodula patellifera* (Preying mantis) and *Eocanthecona furcellata* (Pentatomidae).

3. THE DAINCHA LOOPER *Semiothisa pervolgata* (Fig. 65.35)

The moth is distributed throughout India and is a specific pest of the green manure crop daincha (*Sesbania bispinosa*). The looper larvae feed on the leaves and defoliate the plants resulting in loss of green matter.



▲ **Fig. 65.35** *Semiothisa pervolgata. Adults Female and Male (S. Venugopal, 1957)*

The moth is whitish brown with dark wavy lines and spots. The bluish green oval eggs are laid by the female singly on tender shoots and leaves. A female lays as many as 290 eggs. The incubation period is three to four days. The larva is a looper, greenish with white lines and when full-grown becomes pink with horizontal bands of violet patches dorsally on the abdominal segments. It measures about 27 mm. Larval period lasts for 10 to 12 days. It pupates in the soil and the adult emerges in six to eight days. The total life cycle varies from 20 to 23 days. In Coimbatore four broods occur during the period February-April and June-November.

The larva is parasitised by a braconid *Apanteles hypsipylae.* The pentatomid bugs *Eocanthecona furcellata* and *Andrallus spinidens* are predaceous on the larvae.

Superfamily CALLIDULOIDEA

Moths are without tympanal organs and maxillary palpi. They have chaetosma, proboscis, simple or pectinate antennae and a small frenulum. It includes the following two families.

Family Pterothysanidae

Moths resemble geometrids and are found in the Oriental and African regions. They have a slender body and large wings. In the Oriental region *Pterothysanus* is prevalent and is characterised by long double hair-fringe on the inner margin of the hindwings. In India, eastern Himalayan mountains are inhabited by this insect.

Family Callidulidae

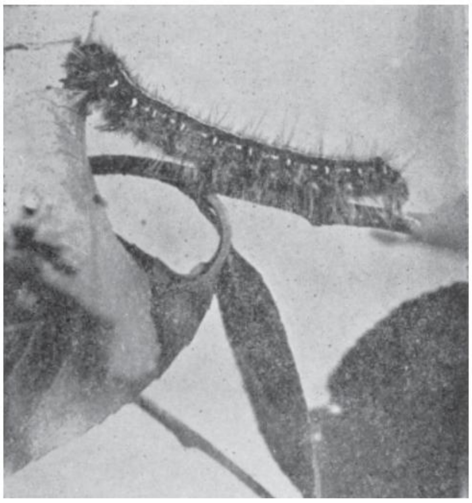
These moths resemble small butterflies and are seen in the Orient. They are day-flying insects and inhabit the hills.

Superfamily BOMBYCOIDEA

Members of this superfamily do not possess maxillary palpi, tympanal organs and chaetosema. Antennae are pectinate, especially in males. Frenulum is vestigial or atrophied and proboscis may be rarely developed.

Family Lasiocampidae (eggars, lappet moths)

The moths are stout, moderate to large sized. They are densely covered with scales. They are abundant in the tropics. Ocelli are absent and the proboscis is atrophied. On the hindwings the humeral lobe is prominent. In the females the anal end possesses tufts of hairs. Larvae are stout with densely covered secondary hairs, which obscure the primitive setae and often laterally possess downwardly projecting hairflanges and hairy tufts dorsally on the anterior segments.



▲ **Fig. 65.36** *Test caterpillar Malacosoma americana (courtesy : USDA. Washington)*

▲ **Fig. 65.37** *Tent caterpillar in web (ibid)*

This family includes the "tent caterpillar" pest, *Malacosoma americana* (Fig. 65.36 & Fig. 65.37) and the Lackey moth of Europe, *M. neustria.* In India a few species are known to infest crops. *Taragama siva* is a sporadic pest on mahogany, *Acacia arabica*, rose, *Zizyphus jujuba, Polyalthia longifolia*, moringa and *Tamarix gallica. Trabala vishnou* feeds on castor, *Syzigium jambolanum, Terminalia catappa*, rose and *Quisqualis indica*, geranium, etc. *Metanastria hyrtaca* is an occasional pest on a number of crops. *Lenodera vittata* is one of the important hairy caterpillar pests of cardamom in Kerala. *Malacosoma indicum, Suana concolor, Estigena pardalis* and *Nodiasa siva* are other Indian species.

1. THE CARDAMOM LEAF CATERPILLAR *Lenodera vittata*

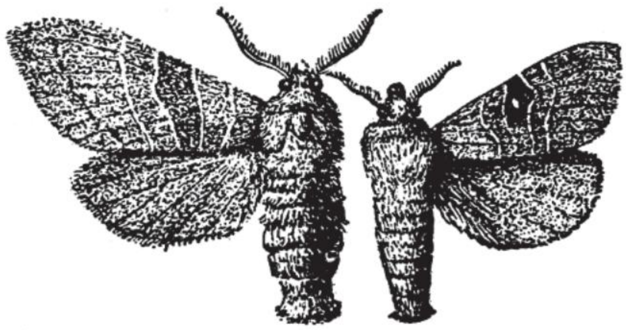
It occurs on cardamom during August to December and larvae feed on leaves of clumps leaving pseudostems and midribs. Heavy defoliation is noticeable in widely scattered patches.

Moths emerge in June, mate and lay the eggs on cardamom leaves. The moth lays the cream coloured dome shaped eggs on both surfaces of the leaf in a row. A female lays 100 to 130 eggs in six to nine days. The incubation period is 10 to 13 days. There are six larval instars and the full-grown larva measures 106 to 110 mm. Larval period lasts for 112 to 118 days. It pupates in the loose soil in an earthen cell at a depth of 5 to 8 cm. The pupal stage lasts for five to seven months. The larvae are parasitised by a tachinid fly *Carcelia kockiana.*

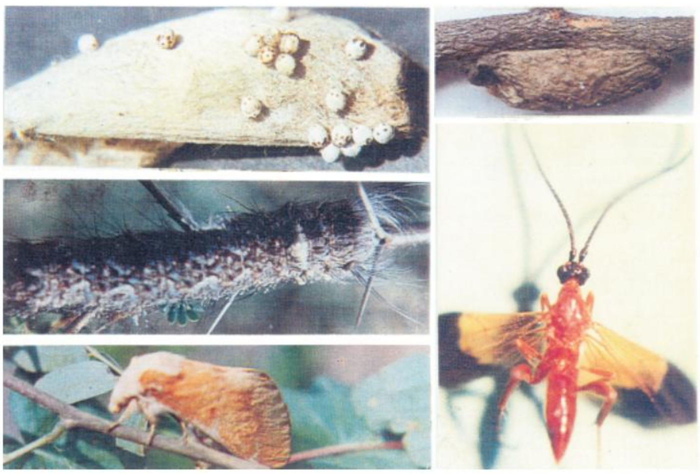
2. THE HAIRY CATERPILLAR *Metanastria hyrtaca*

The insect (Fig. 65.38 & 39) is distributed in India and Sri Lanka. Larvae feed on the leaves of trees and plants and sometimes the damage caused is serious. This is a sporadic defoliator of cashew trees in India.

The moth is stout and fairly big with grey brown wings. Male possesses pectinate antennae and in the female they are smaller and thinner. The forewing of male has a black patch with a white spot in the centre of it. In the female the wings are longer and broader with wavy lines across them and without a black patch. The female lays as many as 140 eggs in groups or rows on the lower surface of leaves or twigs. The egg is spherical and dull white with two brownish-black markings. The incubation period is 9 to 12 days.



▲ **Fig. 65.38** *Metanastria hyrtaca adult, female and male*



▲ **Fig. 65.39** *Metanastria hyrtaca. Left: Top—Eggs; Middle—Larva; Bottom—Adult; Right: Top- Parasitised cocoon; Bottom—Parasite Microdus fumipennis (courtesy: T.N. Ananthakrishnan, 1994.)*

The larva feeds on the leaves and as it grows it becomes a voracious feeder. The larva becomes full-grown in 45 to 60 days. It measures 65 mm long, is stout, hairy, and cylindrical, though slightly flattened ventrally. Head is small and black with a dorso-median brownish band extending up to second abdominal segment. The body is greyish-black or greyish-dark brown with hairs of different colours and sizes. It pupates on the stem or leaf in a loose cocoon of silk interwoven with hairs from its body; often two or more may be seen in a group. The adult emerges in 9 to 18 days. The total life cycle occupies 75 to 109 days depending on weather.

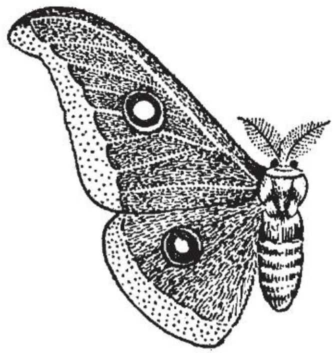
It breeds on *Terminalia catappa, Mimusops elengi, Achras zapota, Guazuma tomentosa, Nyctanthes arbortristis, Bassia longifolia, Schima wallichii, Syzigium jambolanum, Acacia arabica, Albizzia stipulata, Anthocephalus cadamba* and *Moringa oleifera.*

Burning the larvae found in groups on trees with torches or spraying fish oil rosin soap or cypermethrin 0.02% or carbaryl 0.1% or monocrotophos 0.05% controls the pest.

Family Saturniidae

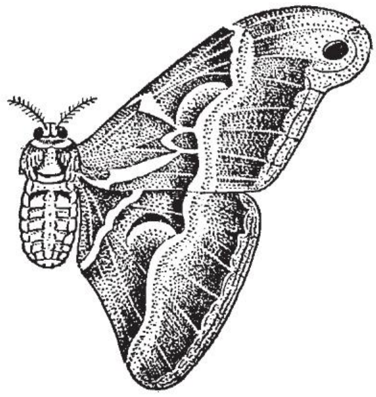
The insects are large and found mainly in tropical countries, a few being present in temperate regions. Both sexes have pectinate antennae, the rami being longest in the males. Labial palpi are very small and frenulum is wanting. Almost all moths have a transparent eye-spot near the centre of each wing. The larvae are stout and smooth and possession of scoli is a characteristic feature not met with in other families. The position and number of scoli are of some taxonomic importance. The larva pupates in a dense firm cocoon, which in several species yields silk of commercial value.

The largest European lepidopterous insect is *Saturnia pyri.* Females of *Atlas atlas* and *A. edwardsi* have a wing expanse of 25 cm and are included among the largest moths in the world. Shantung silk is obtained from the oak silk worm *Antheraea pernyi* of China. The Japanese oak silkworm *A. yamamai* is reared on a large scale in Japan.



▲ **Fig. 65.40** *Tasar silk moth Antheraea mylitta (Lefroy)*

In the Oriental region the brownish Tasar silk is yielded by *Antheraea mylitta* (Fig. 65.40), which is uni- or bi-voltine. In Assam Muga silk is obtained from the semi-domesticated species *Antheraea assamia,* which is multivoltine. The oak tasar silkworm is *A. proylei.* In Assam and Bengal *Samia cynthia ricini,* (Fig. 65.41), a multi-voltine species, yields Eri silk and is reared on castor. A few are pests of crops. *Cricula trifenestrata* feeds on the foliage of mango, cashew, pepper, *Terminalia* and tea. The larvae of the moon moth *Actias selene* feed on leaves of *Moringa oleifera, Odina wodier*, wild cherry, *Betula alnoides*, apple, pear, walnut, etc. and defoliate them completely. The other species found are *Loepa newara* and *Salassa lola.*



▲ **Fig. 65.41** *Samia cynthia ricini, adult (ibid)*

Family Brahmaeidae

The family consists of a very small group of moths found in the tropics. They are characterised by the presence of proboscis and large upturned labial palpi. *Brahmaea wallichii* and *B. hearseyi* occur in India in hilly forest areas.

Family Bombycidae (including Eupterotidae)

These insects are mainly Ethiopian and Oriental in distribution. Both sexes have pectinate antennae. *Eupterote* and its allies have a frenulum and their larvae have tufted long hairs and numerous secondary setae but verrucae are absent. *Bombyx* and related genera lack a frenulum and their larvae are elongate and glabrous with usually a medio-dorsal horn on the eighth abdominal segment. They pupate in dense silken cocoons and the well-known silkworm of commerce is *Bombyx mori.* The insect has been introduced into many parts of the world from China and is now entirely domesticated. It is reared on mulberry for its silk, which may be white or yellow. "Silkworm gut" is the dried silk extracted by desiccation from the silk glands of the larva.

A few species are of importance as pests of crops. *Nisaga simplex* feeds on rice and grasses. Larvae of *Ocinara varians* feed on leaves of *Ficus* spp. Larvae of *Eupterote* spp. are serious pests of moringa, cardamom and coffee in South India.

1. THE MORINGA HAIRY CATERPILLAR *Eupterote mollifera*

The adult moth (Fig. 65.28) is yellow with faint lines and lays the eggs in groups on tender portions of trees. The larvae are hairy and brownish in colour and feed on leaves voraciously defoliating them quickly. When grown up they collect on tree trunk in groups. The hairs are irritating to touch. They pupate in the soil. Burning the larvae, which congregate on tree trunk or spraying fish oil rosin soap or parathion 0.05 % may be useful in controlling the pest. *Eupterote geminata* also occurs on moringa.

2. THE CARDAMOM HAIRY CATERPILLARS *Eupterote spp.*

The larvae of *Eupterote cardamomi, E. canaraica, E. fabia* and *E. testacea* feed voraciously on leaves of cardamom and cause wholesale defoliation of plantations. Similar damage is caused on coffee by *E. fabia* and *E. canaraica.* These assume pest proportions only in certain years and are usually sporadic pests.

a. Eupterote cardamomi The moths emerge in June-July just after the commencement of South-West monsoon. The female moth lays the eggs in flat masses on the undersurface of leaves of shade trees and a female lays as high as 837 eggs, the average being 400 to 500 eggs. Each egg mass contains about 50 to 160 eggs. Egg is yellowish and dome-shaped. Incubation period is 15 to 17 days. The larva passes through ten instars and measures 62 mm long. The larval stage is about 140 to 151 days. It pupates in the soil in a silken cocoon with particles of sand, debris, short urticating hairs, etc. adhered to it at a depth of 5 to 8 cm. The pupal period lasts for seven to eight months. Longevity of adult moths is about 20 days.

The larvae up to the sixth or seventh instar stage feed on the leaves of shade trees and thereafter with the cessation of monsoon fall down in large numbers suspended by silken threads on to cardamom plants. The larvae defoliate the cardamom plants causing shrivelling up of plants which ultimately affects the yield also. It is a sporadic pest. Apart from cardamom it infests *Polygonum chinense. Solatium giganteum* and *Macaranga indica.* Larvae of the insect are parasitised by *Sturmia sericariae* (Tachinidae) and *Aphanistes eupterote* (Ichneumonidae).

b. Eupterote canaraica A female lays on an average 480 eggs in flat masses, each mass containing 40 to 120 eggs, in 9 to 12 days. Egg is pale yellow and hemi-spherical and incubation period is 20 days. There are seven larval instars lasting for 130 to 137 days. Full-grown larva measures about 62 mm long and pupates in the soil in a silken cocoon. Pupal stage lasts for seven to eight months. Longevity of adult is 30 days. Apart from cardamom *Erythrina indica, Tectona grandis, Solanum giganteum, Macaranga indica* and *Trema orientalis* are infested. Larvae are parasitised by the tachinid *Sturmia saricariae.*

c. Eupterote testacea Moths emerge in June-July. The female lays about 300 to 350 pale yellowish hemispherical eggs in clusters. The eggs are laid in eight to nine days. Each egg cluster contains 62 to 90 eggs. Incubation period is 13 to 15 days. There are seven larval instars and the larval period lasts for 97 to 100 days. The larva measures about 72 mm and pupates in a cocoon in the soil. Pupal period is about seven to eight months. Larva feeds on *Erythrina indica, Lablab niger* and *Polygonum chinense.*

d. Eupterote fabia Life history and habits are similar to the species mentioned above. Full-grown larva measures 75 mm. Larva feeds on cardamom and *Tectona grandis. Sturmia sericariae* is parasitic on larva.

Control: The above mentioned hairy caterpillar pests can be controlled by spraying cypermethrin 0.025% or fenvalerate 0.02% or deltamethrin 0.0025%. Light digging or raking of the soil 15 to 20 cm deep in January-February helps in locating and destroying the pupating larvae and pupae. During September-November the larvae of *E. canaraica* and *E. cardamomi* are infested by a fungus *Beauveria bassiana.*

The other families, which are not economically important, include Anthelidae, Citharoniidae (Ceratocampidae), Lacosomidae (Perophoridae), Lemoniidae, Endromididae, etc.

Superfamily SPHINGOIDEA

Adults are with well-developed proboscis and frenulum, and without tympanal organs. Antennae are apically pointed and usually hooked. This includes a single family Sphingidae.

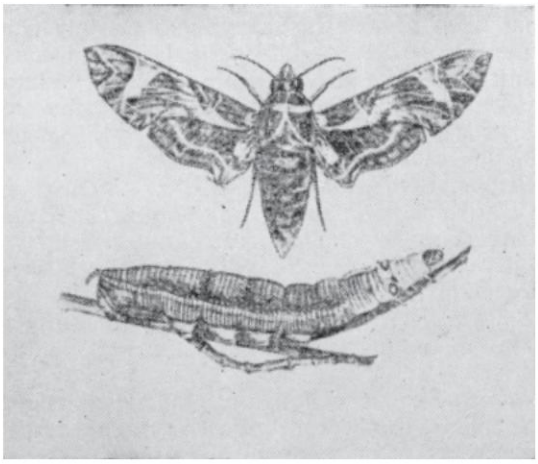
Family Sphingidae

The insects are widely distributed throughout the world but abundatant in tropical regions. They range in size from medium to very large moths. The forewings are elongate, the outer margin being very oblique. The antennae in the males are ciliated with partial whorls. Generally they are thickened towards and beyond the middle and pointed apically. The moths are mostly crepuscular or nocturnal. A few such as *Macroglossa, Hemaris,* etc. are diurnal. These insects are powerful fliers.

The larvae are generally smooth and a dorsal horn is present on the eighth abdominal segment. They pupate in the soil in an earthen cocoon.

▲ **Fig. 65.42** *Acherontia styx*

The adult of the death's head moth *Acherontia styx* in India is a remarkable species. It enters beehives and sucks honey. It is also capable of producing a shrill chirping sound. *Acherontia styx* (Fig. 65.42) and *A. lachesis* on *Lablab niger*, *Sesamum indicum* and *Solanum melongena ; Daphnis nerii* (Fig. 65.43) on *Nerium odorum*; *Hippotion oldenlandiae* on colocasia; *H. celerio* on grapevine; *Herse convolvuli* on sweet potato and green gram; and *Macroglossa vialis* and *Rhopalopsyche bifasciata* on *Morinda tinctoria* are some common sphingids in India.



▲ **Fig. 65.43** *Daphnis nerii, A-adult, B-larva (T.B. Fletcher, 1914)*

Superfamily NOCTUOIDEA

Moths of this superfamily possess minute maxillary palpi and the tympanal organs lie in metathorax. The vein C_2 is absent in both wings. Most of these insects are economically very important as pests of crops. It includes the following families: Notodontidae, Amatidae, Arctiidae, Agaristidae, Noctuidae, Lymantriidae and Hypsidae.

Family Notodontidae

The moths are moderately stout-bodied insects with elongate forewings and are nocturnal. When at rest the wings are folded roof-like over the body. In some genera such as *Notodonta*, *Lophopteryx* and others the forewings have tufts of scales arising from the middle of the hind margin of forewings and hence the family name Notodontidae. The larvae are gregarious and feed on trees and shrubs. The larva has shorter forelegs, the second and third thoracic legs are longer; the anal end is inflated with the anal claspers modified into two slender processes. When disturbed it attaches itself to the host by the four pairs of prolegs and elevates the anterior and posterior ends of the body. The moth remains in this curious attitude without making any movement, resembling a spider, or crumpled leaf, or a twig with unopened buds. In some cases the larva possesses a pair of roughened tubercles on the prothorax and on the metathorax a fleshy protuberance. A ventral prothoracic gland is present in the larva, which ejects an irritating fluid. In *Dicranura vinula* this fluid consists of formic acid. In Malaysia, the adult of *Tarsolepis sommeri* is known to frequent the eyes of human beings.

In South India, the crab caterpillar *Stauropus alternus* is a pest on pigeon pea, tamarind and *Cassia auriculata.* Larva of *Dinara combusta* feeds on leaves of maize, sorghum and rice in small numbers in India.

Family Amatidae (Syntomidae)

These are tropical insects, small to medium sized, day-flying and usually inactive. Many are wasp-like in appearance resembling sawflies and other Hymenoptera and are brightly coloured. The larva is short with verrucae bearing numerous setae. It pupates in a cocoon of felted hairs and silk.

In India *Euchromia polymena* is a common species and infests sweet potato. *Amata passalis, Psychotoe dwauceli* and *Ceryx godarti* are other species common in India.

Family Arctiidae [Lithosiidae] (tiger moths, footman moths)

These are mostly tropical insects with stout body and moderately broad brightly coloured wings with spots or bands on them. They are nocturnal and species of several genera are capable of producing of sound. The larvae of Arctiinae are densely clothed with long hairs and feed on herbaceous plants. Their cocoons are made up of larval hairs and silk. The larvae of Lithosiinae are sparsely hairy and feed on lichens. The larvae of Nycteolinae are not prominently hairy and pupate in boat shaped cocoons. They feed on leaves and fruiting bodies of plants.

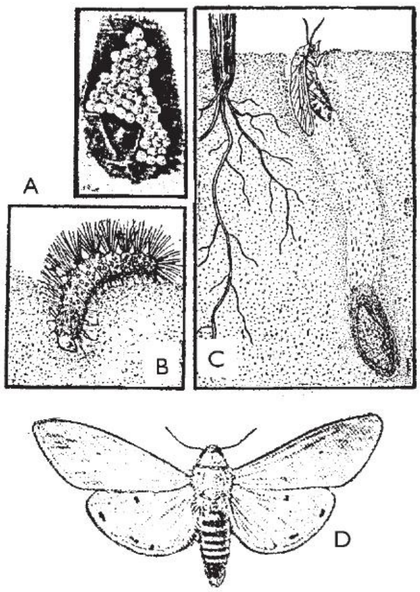
1. THE BIHAR HAIRY CATERPILLAR *Spilarctia (=Spilosoma) obliqua* Walker

It is a pest of pea, cotton, jute, sunnhemp, *Sesamum indicum, Eleusine coracana,* chrysanthemum, mulberry, castor, cauliflower, cabbage, lettuce, lucerne, *Phaseolus radiatus, Pennisetum typhoideum, Abutilon indicum, Dioscorea bulbifera,* linseed, maize, groundnut, sunflower, tobacco, turmeric, mustard, soybean, lantana, sweet potato, lablab, cowpea, etc. It has been reported to feed on 96 plant species in India. It is a serious pest of jute in Bengal, Bihar, Orissa and Assam and sunflower in Punjab.

The eggs are laid in batches on the undersurface of leaves. The dull greenish spherical egg measures 0.57 mm and a female lays as high as 1885 eggs. The incubation period varies from 3-12 days. There are six larval instars. The full-grown larva is darkened with yellowish brown abdomen having numerous pale-white, brown and black hairs and measures about 43 mm. The larval period varies from 17-51 days depending on weather. The larvae defoliate the plants and move from one field to another. They pupate in the soil. Before entering the pre-pupal stage the larva stops feeding and spins loose cocoon mixed with hairs from its body. The pre-pupal stage lasts for three to seven days. The pupa is reddish brown and the pupal period varies from 10 days in summer to 68 days in winter. The adult is dull yellow with oblique line of black dots on hind wings. The dorsal side of abdomen is red with dull yellow ventral side. The adults emerge in the night and early hours of morning. There are six overlapping generations in a year, which varies from 38 days during summer to 128 days during winter.

2. THE RED HAIRY CATERPILLARS *Amsacta albistriga and A. moorei* (Fig. 65.44)

The insects are distributed all over India. *Amsacta moorei* is common in North India whereas *A. albistriga* is the predominant species in the South, especially in Tamil Nadu. In South India this has been recorded as a very serious pest of dry crops especially groundnut, in most of the rain-fed tracts for the past five decades. The essential prerequisite for mass emergence is the onset of showers, which are followed by bountiful supply of food material for the progeny. Certain marked variations exist from tract to tract in the seasonal, climatic and other environmental factors. The local agricultural practices have to be adjusted according to these factors. The pest has also adapted itself to a perceptible degree in its seasonal occurrence, feeding habits, extent of damage it causes, etc. Both the species occur together.



▲ **Fig. 65.44** *Amsacta albistriga. A—Egg mass, B—Grown up larva entering soil for pupation, C—Pupa in the soil and emergence of moth, D—Adult (H.S. Pruthi, 1969)*

Life history: The adult moth is medium-sized having white forewings with brownish markings and streaks and white hindwings with black spots. There is a yellow band on the head as also a yellow streak along the anterior margin of the forewings in *A. albistriga* and the markings are red in *A. moorei.* Moths emerge on the second day by 4 p.m. after the receipt of copious rains. The emergence occurs in waves following subsequent rains. The adults pair almost immediately after the emergence and oviposit the same night. Oviposition is spread over two to three days. The eggs are cream or bright yellow and are laid in masses on the standing crop of cowpea or groundnut on the lower surface of leaves. The eggs may be laid on the soil, clods of earth, stones, wood pieces and occasionally on other vegetation. A moth may lay as many as 2300 eggs in six days, the average being 600 to 700. The larvae hatch from the eggs in three or four days and the dark larvae feed gregariously on the lower surface of leaves scraping them for four or five days. In about 10 days they attain an ashy brown colour and slowly spread from plant to plant feeding voraciously. In about 40 to 50 days the larvae become full grown. They are reddish brown with black patches at either end of the body and have long hairs arising from verrucae on the body. The larvae feed on the leaves of plants in large numbers and march from field to field in thousands. In an area where there is an outbreak, the entire crop will look as though grazed by cattle. The full-grown larva awaits the next sharp showers, after which, they burrow into the soil and pupate along bunds, shady moist places under trees, etc., at a depth of 10 to 20 cm. Failure of rains at this critical stage may result in annihilation of the larvae, as they may not be able to pupate for want of sufficient moisture. The pupae remain in the soil till next year. In Pollachi (Tamil Nadu) apart from an emergence in May, another distinct emergence has been noticed in September, possibly from those pupated in July. Similar instance of short-cycle emergences has also been observed in Madurai.

The larvae, apart from groundnut, feed on cowpea, sorghum, *Pennisetum typhoideum, Eleusine coracana*, cotton, castor, *Rhynchosia minima, Commelina bengalensis, Portulaca,* sp., *Chloris barbata, Euphorbia tirucalli, Croton sparsiflorus. Cassia auriculata*, etc.

Control: As the incidence of the pest is widespread over vast areas and the damage devastating, the farmers in those areas have necessarily to take up the control measures on a co-operative basis.

During summer ploughings the pupae must be collected and destroyed. As the mass scale emergence of moths takes place on the second day after copious rains, bonfires or setting up of light traps must be done. The moths, which are attracted to light up to 11 p.m., are collected and destroyed. The egg masses are also to be collected and destroyed.

Dusting methyl parathion 2% dust at 20 kg/ha a week after large-scale emergence kills the early instar larvae. Grown up larvae are killed by spraying cypermethrin 0.05% or fenvalerate 0.05% or methyl parathion 0.05%. Those not killed may be collected and destroyed. Nuclear polyhedrosis virus has been found promising in field scale control.

Natural enemies: Cotesia flavipes, Glyptapanteles creatonoti, Apanteles bosei (Braconidae), *Exorista civiloides, Sturmia inconspicuella, Tachina fallax* (Tachinidae), on larvae and a phorid fly *Megaselia scalaris* on prepupa are parasitic. The pentatomid bug *Eocanthecona furcellata* is predaceous on the larvae in the field. A nematode *Mermis indica* infects the larvae of *A. albistriga.* The larvae are infested by the fungus *Aspergillus fumigatus.*

3. THE BLACK WOOLLY CATERPILLAR *Amsacta lactinea* Cramer

This species is widely distributed in India, Myanmar, Sri Lanka, China and Java. It is a pest of agricultural and forest plants. Its host plants include *Cassia tora, Clerodendrum infortunatum, Coffea arabica, Colocasia* sp., *Corchorus capsularis, Crotalaria juncea, C. stricta, Derris elliptica, Dioscorea* sp., *Dolichos biflorus, Eleusine coracana, Gossypium hirsutum, Helianthus annuus, Heliotropium* sp., *Ipomoea batatas, Lantana* sp., *Menispermum glabrum, Oryza sativa, Pennisetum typhoideum, Phaseolus mungo, Ricinus communis, Sorgum bicolor (=S. vulgare), Tectona grandis, Vitex negundo, Zea mays,* etc. It is of special interest because it is a serious defoliator of *bhalia (Moghania macrophylla)* an important bushy host of the lac insect *Kerria lacca.*

Newly hatched larvae prefer to feed gregariously and skeletonise the leaf surface. Later, they disperse and consume entire leaves. During severe infestation the plants are completely denuded of the foliage, and their growth is checked. It is active during monsoon period. The eggs are laid in masses of 250-500 indiscriminately on the leaves and hatch in about four days. Pre-oviposition period is one to two days. There are seven larval instars, the larval period being 25 to 32 days. The larva pupates in the soil and the pupal stage lasts for 10.4 to 26.6 days when winter does not intervene and 215.4 days when winter intervenes. In Uttar Pradesh three overlapping generations are noticed; first two covering 41.1 and 60.2 days respectively, the third covering 57.8 days when winter does not intervene but occupies 252.6 days when winter intervenes.

4. THE SUNNHEMP HAIRY CATERPILLAR *Utetheisa pulchella* (Fig. 65.28)

The insect is distributed in India, Sri Lanka, Africa, Europe, Philippines, New Guinea, Malay Archipelago and Australia. The moth is medium sized, white with red and black spots on the forewings. The female lays about 80 to 100 round, smooth yellow eggs on leaves singly or in small groups. The larva has yellow lines dorsally and dorso-laterally and black stripes and orange patches laterally and a brown head. It has long brownish hairs on its body. The larvae feed on leaves of *Crotalaria juncea* and defoliate the plants. The damage is much more serious in the later stages when they bore into pods and feed on the seeds. It pupates in the soil. The total life cycle takes 27 to 31 days, the egg, larval and pupal periods being 3 to 4, 18 to 21 and 6 to 8 days respectively.

It breeds on sunnhemp (*Crotalaria juncea*), *Crotalaria striata* and *Heliotropium indicum.*

Its natural enemies include *Bracon brevicornis* (Braconidae), *Padomyia setosa* and *Drino inconspicua* (Tachinidae) on larvae and *Phanurus* sp. on eggs.

5. THE WOOLLY BEAR *Pericallia ricini*

It is a pest on sweet potato, castor, banana, pumpkin, sesamum, brinjal, cotton, *Lablab niger*, calotropis, oleander, moringa, coccinea, colocasia, *Sesbania grandiflora*, etc. The larva has a red head and is blackish brown with long thick hairs arising on bluish warts. It pupates in a cocoon made of hairs and silk. The moth is grey with dark spots on the pink hindwings.

The other common arctiids found in India are: *Diacrisia nigrifrons*, *Celama internella, Roeselia fola, Creatonotus gangis*, and the cardamom arctiid *Alphaea biguttata.*

Family Agaristidae (Phalaenoididae)

These are mostly tropical insects, diurnal in habit and their colouration and antennal structure differentiate them from Noctuidae. The common Indian species are *Aegocera venulia, A. bimacula* and *Exsula victrix.*

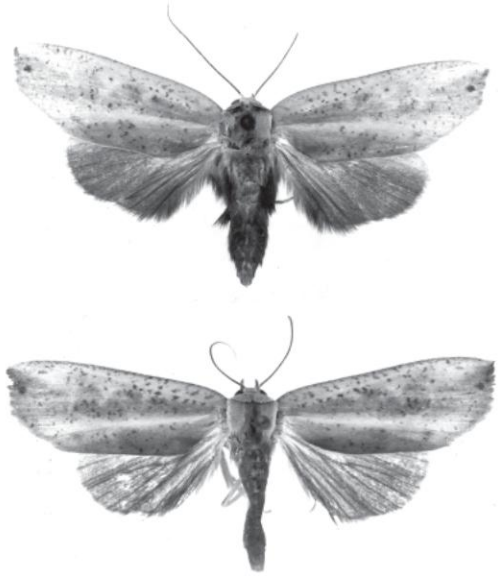
Family Noctuidae

This is a very remarkable family, which includes a large number of species of economic importance. These insects are nocturnal and are attracted to light. A proboscis is present but rarely atrophied. The labial palpi are well developed. A frenulum is present. The insects are generally cryptic and dull coloured.

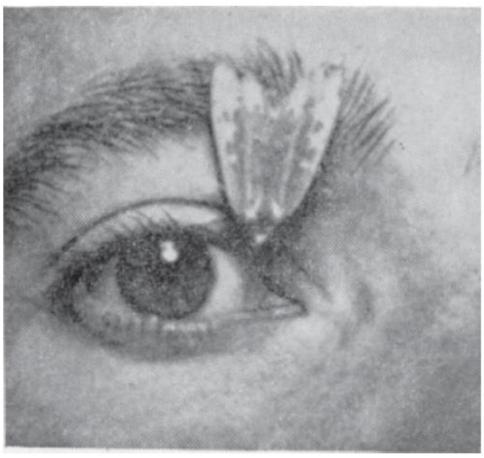
The eggs of noctuids are spherical, generally ribbed, and reticulate.

The larvae in most cases have primary setae on their body and the crochets on prolegs are uni-ordinal in mesoseries. The prolegs are normal in number in most cases, excepting those, which come under the subfamilies Catocalinae, Plusiinae and Hypeninae, where the first or the first two pairs of prolegs are suppressed. The larvae are called the semiloopers. The larvae are mostly phytophagous, often polyphagous and a few are stem borers. The seed capsules of Caryophyllaceae are eaten by *Hadena.* The larvae of *Eublemma amabilis* (Fig.65.28) are predaceous on coccids, especially the lac insect. Lichens are fed upon by *Cryphia* species. The fungi on rotten wood are utilised by *Parascotia fuliginaria.* The larvae generally pupate in the soil in an earthen cell. However, *Plusia* and its allies pupate in silken cocoons.

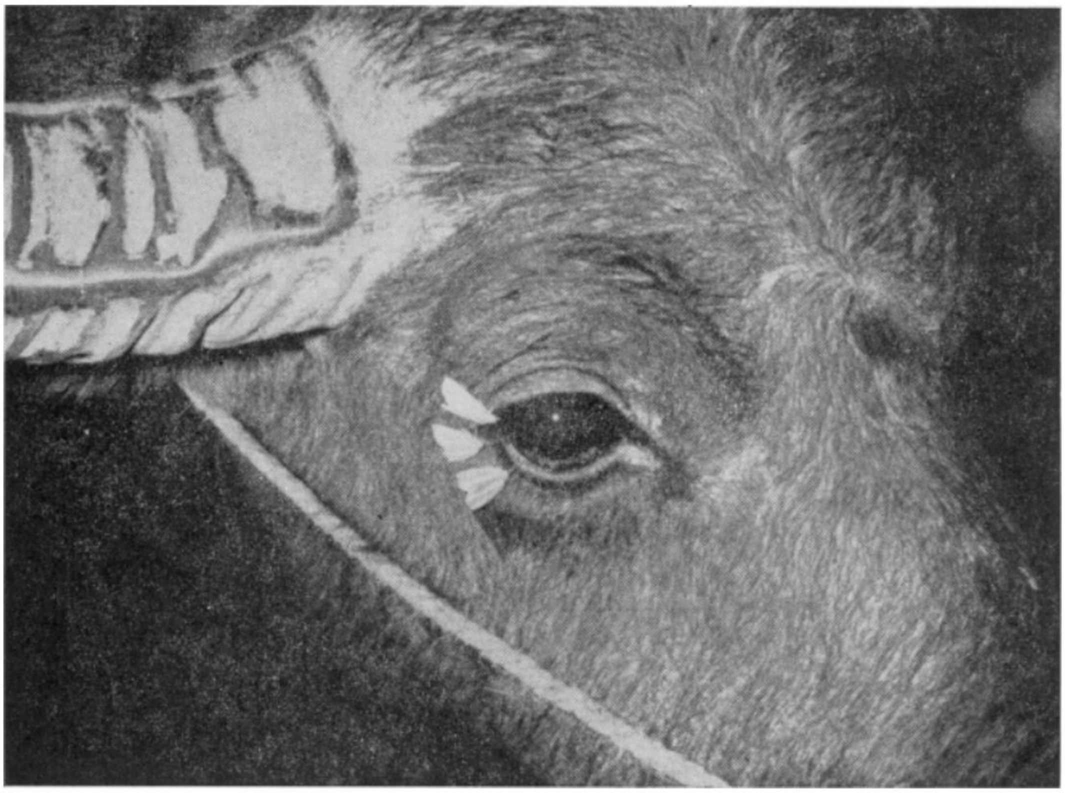
In their adult stage a few noctuids are known to pierce the fruits and this causes rotting and premature fruit fall. The common fruit-piercing moths in India are: *Othreis fullonica* and *O. materna* on oranges, mango, pomegranate, pummelo, etc. *Othreis homaena*, *Calpe emarginata* and *Anua coronata* are other moths found in company with the above occasionally. Interestingly, the adults of a few species are known to frequent the eyes of man and animals for their lachrymal secretions. Among such species, the most common one is *Lobocraspis griseifusa* (Fig. 65.45), which frequents the eyes of man (Fig. 65.46) in Thailand and Myanmar, of cattle and water buffalo (Fig. 65.47) in Bangladesh and Africa, of cattle,



▲ **Fig. 65.45** *Lobocraspis griseifusa, male and female (courtesy: W. Buttiker, Ciba-Geigy, Switzerland)*



▲ **Fig. 65.46** *Lobocraspis griseifusa feeding on lachrymal secretions of human eye (courtesy :Banzinger and Buttiker, J. Med. Ent.)*



▲ **Fig. 65.47** *Lobocraspis griseifusa adults feeding on lachrymal secretions of buffalo (courtesy: W. Buttiker, Ciba-Geigy, Switzerland)*

water buffalo and sambar in Thailand and of cattle in Myanmar. *Arcyophora bothrophora, Calpe eustrigata, Mocis frugalis* and *Hypena* sp. in Bangladesh and *Calpe minuticornis* in Cambodia are found on eyes of cattle and pig in Thailand. The eyes of pigs in Thailand are frequented by *Hypena conscitalis, Blasticorhinus rivulosa* and *Nanaguna breviuscula*. *Arcyophora icterica* (Fig. 65.48) frequents the eyes of man, cattle, water buffalo, horse, mule and donkey in South India and of cattle and spotted deer (*Axis axis*) in Nepal. *Arcyophora zunderi*, *A. patricula* and *A. longivalvis* are found on the eyes of cattle, horse and donkey in Africa. *Arycophora sylvatica* attacks the eyes of man, cattle, water buffalo and sambar in Thailand and of cattle and water buffalo in Africa. The moth of *Calpe eustrigata* frequently pierces the skin of buffalo, sambar deer, Malayan tapir and Nilgai antelope and feeds on blood.

▲ **Fig. 65.48** *Arcyophora icterica, the eye-frequenting noctuid found in South India (courtesy: W. Buttiker)*

Among the many species that are harmful to cultivated crops the following are of major importance:

1. THE CASTOR SEMILOOPER *Achaea janata* (Fig. 65.28)

This is one of the important pests of castor in India. The larvae defoliate the plants within a very short period leaving only the veins of leaves. Apart from castor it feeds on rose, pomegranate, *Euphorbia hirta, E. hypersifolia, Tridax procumbens, Ficus bengalensis, Bauhinia* sp., *Zizyphus* sp. and *Cardiospermum helicacabum.* It occurs from August to January. Another semilooper, *Paralellia algira* is also found on castor in company with this occasionally.

Life History: The eggs are round, blue-green in colour and ridged. They are laid on the undersurface of leaves singly and one to six eggs are found on a leaf. A female is capable of laying about 450 eggs. The incubation period is two to five days. The first instar larva is slender and yellowish green in colour. The full-grown larva measures 60 to 65 mm with a black head and the first pair of prolegs are non-functional and hence a semilooper. The apex of the loop is conspicuously black with a red spot on it, and anal tubercles are red. Colour variations in larvae are also noticed. Some are grey with lateral red or brown stripes and others are black with lateral white stripes. The larvae are gregarious and feed voraciously on leaves. The larval period ranges from 11 to 15 days. It pupates in the soil or among fallen leaves. Pupation rarely occurs in leaf folds on the plant. Pupal stage lasts for

10 to 14 days in warm weather and may occupy a few months in cold weather. The moth is pale reddish-brown with hindwings black with a medial white band and three large white spots on outer margin.

Natural enemies: The larvae are parasitised by *Euplectrus leucostomus*, *Tetrastichus ophisuae* (Eulophidae), *Apanteles ruidis, A. subndinus, Microplitis ophisuae, M. ensirus, M. maculipennis* (Braconidae), *Zamesochorus orientalis, Paniscus ocellaris* and *Henicospilus* sp. (Ichneumonidae).

Control: Hand picking and destruction of larvae may be useful. Spraying of chemicals like parathion, carbaryl, DDVP, chlorpyrifos, endosulfan, cypermethrin, etc. controls the pest.

2. FIELD BEAN POD BORER *Adisura atkinsoni* (Fig. 65.28)

This insect is one of the important pests of pulses in South India. It attacks field *Lablab niger* and pigeon pea. The larva feeds on flower buds and bores into pods feeding on developing seeds.

The adult moth is yellowish with a brown wash and two V-shaped specks on forewings and the hindwings white with pale brown markings. A female is capable of laying 289 to 955 eggs. The larva is green and resembles that of *Helicoverpa armigera*. However, it can easily be distinguished by the brown lateral markings and slightly humped condition of the anal segment. It pupates in the soil. The egg, larval and pupal periods in the short life cycle individuals varies from 2 to 3 days, 12 to 19 days and 8 to 18 days respectively. It hibernates in the pupal stage from February to November.

The larvae are parasitised by *Bracon* sp. and a Tachinid, *Carcelia evolans kockiana*.

Control: Dusting methyl parathion 2% dust at 25 kg/ha or spraying cypermethrin 0.025% or deltamethrin 0.0025% or fenvalerate 0.05% brings about control of the pest. Drenching the soil before planting potato tubers with chlorpyrifos 0.10% emulsion affords protection.

3. THE GREASY CUTWORM *Agrotis ipsilon*

The insect is found in America, Australia, Pacific Islands and India.

The cutworm is polyphagous and infests potato, barley, oats, cabbage, peas, beet root, Bengal gram (*Cicer arietinum*), tobacco, mustard, linseed, lady's finger, brinjal, rice, pulses, snakegourd, etc. The larvae remain concealed in cracks in the ground and become active during night. The stems of younger plants are cut at a height of about 5 cm from ground level and in this way a large number of plants is damaged. As the plants grow they are cut at a height of about 24 cm from the ground. This results in retardation of growth and ultimate reduction in yield. In potato the damage caused varies from 12 to 35 % in the crop.

The adult moth has dull brownish forewings with numerous wavy lines and spots and fawn-coloured hindwings. The ribbed eggs are laid in clusters of 30 on the undersurface of leaves or on moist soil. A female lays about 300 eggs in 3 to 15 days. The incubation period is 2 to 13 days depending on seasonal conditions. The dark brown larva with a red head becomes full grown in about a month. It pupates in the soil in an earthen cocoon and the adult emerges during day time. Total life cycle occupies 30 to 68 days.

Agrotis ipsilon, A. segetum and *Xestia c-nigrum* occur commonly in South India. *Agrotis flammatra* is found in North India.

Application of chlorpyrifos to the soil before planting minimises damage. The clods in the field should be broken. Flooding of infested fields also controls the pest.

4. THE SNAKEGOURD SEMILOOPER *Anadevidia peponis*

This is a specific pest of snakegourd (*Trichosanthes anguina*) in India. The larvae defoliate the vines.

The moth is brown with shiny brown forewings and lays spherical, white, eggs singly on the undersurface of leaves. The semilooper caterpillar is green with tubercles on the body from which arise thin hairs and its anal segment is humped. It has long white longitudinal stripes on body. When fully grown measures 35 to 40 mm and pupates in a thin white silken cocoon in the leaf fold. The pupa is greenish and turns brownish just before emergence of adult. The life cycle occupies about a month. The larva is parasitised by *Apanteles plusiae.*

Collection and destruction of larvae and pupae may be done. Spray of parathion 0.025 per cent controls it.

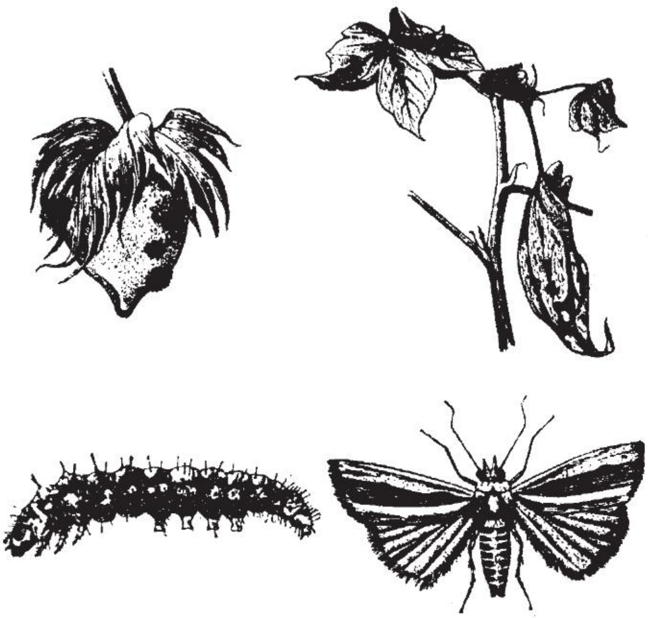
5. THE CHICKPEA SEMILOOPER *Autographa nigrisigna*

It is minor pest of gram, lucerne and peas in India. The eggs are laid singly or in groups of 2-13 on the under surface of green or semi-dried leaves, petioles, tips of branches and sometimes on upper surface of leaves and on stems. A female lays 41-454 eggs, average being 184. The egg measures 0.62-0.67 mm and is spherical, ribbed, reticulate and primrose in colour. The incubation period is two to four days. There are five larval instars, the larval period being 14-18 days. The fully-grown larva measuring 20-22 mm long pupates at the base of plants or in fallen leaves in the ground in a white silken cocoon, the prepupal and pupal periods being respectively 1-2 and 9-11 days. Moths are generally active in the early hours of morning. Fore wings have a 'U' shaped thick golden line associated with cubitus, below which there is an oval golden spot. Hindwings are smoky in colour.

The outer margins of both the wings are lined with a strip of smoky white hairs. Adults live for five to nine days.

6. THE SPOTTED BOLLWORMS *Earias insulana* and *E. vittella*

Earias insulana (Fig. 65.49) is found in West Asia and North Africa whereas *E. vittella* is common in South-East Asia. The pest generally makes its appearance on the cotton crop about six weeks after sowing and initially damages the tender shoot by boring into it, which results in drooping of the shoot. The larvae later on bore into the buds, flowers and bolls and feed on the contents of ovaries. A larva may move out and feed on another bud or boll. The feeding causes severe shedding of flower buds formed early. The lint, when finally the bolls burst, may not be clean. In the crop sown during September-October the shedding of buds and bolls has been maximum during December and the attack on bolls increases from January and reaches the peak by April. In the summer crop the attack is comparatively low. In South India, *E. vittella* occurs in large numbers.



▲ **Fig. 65.49** *Spotted bollworm Earias vittella*. Top (A&B): Attacked cotton boll and shoot; Bottom (C & D): Larva and moth

Life history: The moths are small. The forewings of *E. vittella* are green with a white streak in each and that of *E. insulana* are completely green. The eggs are laid scattered in groups of two or three in leaf axils, bracts and leaf veins on the undersurface. The egg is deep sky blue with light sheen at the top, crown shaped and sculptured. A female lays about 385 eggs. The incubation period is about three days. The larva becomes full-grown in 10 to 12 days. It is possible to distinguish the larvae of the two species from the third instar. The larva of *E. insulana* has extensive creamy colour on its body with well-defined finger-shaped processes and orange dots on the prothorax. *E. vittella* larva is brownish with a white median longitudinal stripe and without finger-shaped processes. It pupates in a dirty white to light brown tough silken cocoon on the plant or in fallen buds and bolls. Adults emerge in seven to ten days. Total life cycle occupies 20 to 22 days.

Apart from cotton they infest *Abutilon indicum, A. hirtum, Abelmoschus esculentus, Althaea rosea, Hibiscus cannabinus, H. vitifolius* and *Malvastrum coromandelianum.*

The following natural enemies have been noticed on *Earias* spp. in India:

Trichogramma chilonis parasitises the eggs. The larval parasites include *Habrobracon hebetor, Bracon lefroyi*, *B. brevicornis, Rhogas testaceus, R. aligharensis, Bassus* sp., *Apanteles* sp., *Phanerotoma hendecasisella* (Braconidae), *Elasmus johnstoni* (Elasmidae), *Actia aegyptia*, *A. hyalinata* (Tachinidae), and *Polyodaspis* sp. (Chloropidae). The wasp *Eumenes petiolata* preys upon the larvae, which are stocked in its nest. The pupae are parasitised by *Chelonus rufus* (Braconidae), *Melcha nursei* (Ichneumonidae), *Chalcis tachardiae*, *C. responsonator*, and *Centrochalcis* sp. (Chalcididae).

The infested shoots as well as fallen buds and bolls should be collected and destroyed. Periodical spray applications with insecticides like carbaryl 50 WP at 2.5 to 3.0 kg/ha or endosulfan 35 EC at 1.5 to 2.0 litres/ha or monocrotophos 36 SL at 1.0 to 1.25 litres/ha or thiodicarb 75 WP at 625 g/ha are effective. Synthetic pyrethroids like deltamethrin at 12.5 to 15 g a.i./ha, cypermethrin at 80 g a.i./ha, and fenvalerate at 100-150 g a.i./ha are also effective. Organo phosphorus compounds like acephate, triazophos, etc. are also effective. Other products found effective are: alanycarb 30 EC (500 g a.i./ha), cyfluthrin 2.5 EC (12.5 to 18.0 g a.i./ha), indoxacarb 14.5 Ec (50-100 g a.i./ha), methofenozide 22.9 EC (200-300 g a.i./ha), flufenoxuron 10 DS (75-100 g a.i./ha), novaluron 10 EC (75-100 g a.i./ ha) and Spinosad 48 EC (75-100 g a.i./ha) and the combinations cypermethrin 50 g + chlorpyrifos 500 g / litre, cypermethrin 30 g + quinalphos 200 g / litre, alphamethrin 10 g + chlorpyrifos 160 g / litre, and deltamethrin 10 g + triazophos 450 g / litre have also been found effective.

7. THE AILANTHUS DEFOLIATOR *Eligma narcissus indica* Roth (Fig. 65.50)

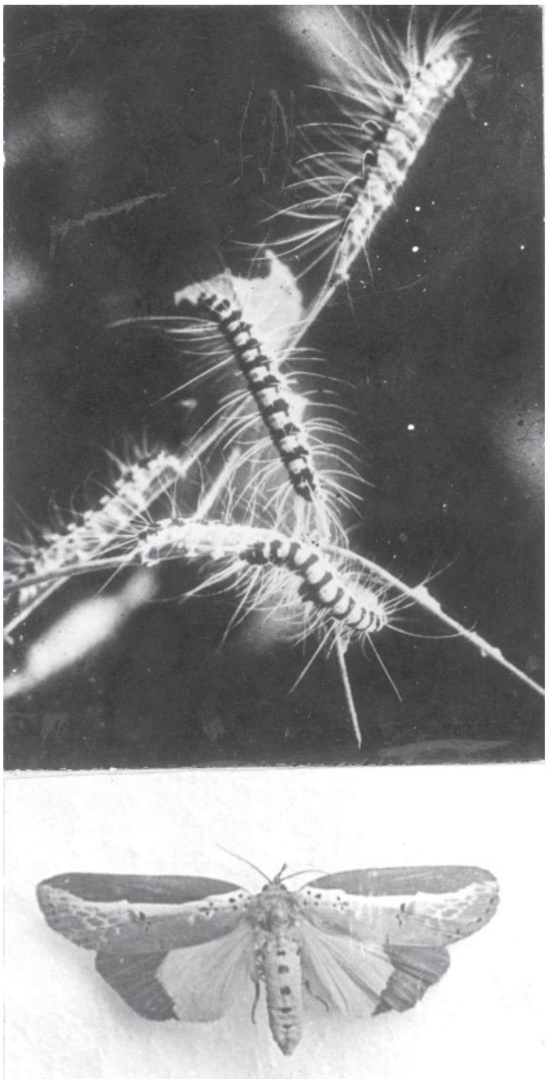
This species is found all over India, China, Myanmar, Andamans, Malaysia, and Compodia.

Nature of damage: Larvae cause defoliation by feeding on both young and mature leaves of *Ailanthus* spp. During heavy infestation, as many as 20-40 larvae can be seen on the rachis of a compound leaf. In nurseries the defoliated seedlings put forth new leaves in about two weeks time but repeated defoliation retards growth of the plants. When all the leaves are eaten up, larvae may sometimes feed on the green parts of the stem. Pest incidence in older plantations is rare compared to young plantations.

Host plants: Ailanthus triphysa and *A. excelsa* (both from India), *A. glandulosa* (in China), *A. curzii* (in Myanmar and Andamans), *A. fauveliana* (in Compodia), *A. mollis* (in Eastern Malaysia) and *A. moluccana* (in Molluccas).

Life cycle: Female moth lays eggs in groups of 5- 55 on the under surface of the tender leaves. There are five larval instars and normally larval period is 22-23 days. Mature larva is bright yellow in colour with black bands on the dorsal surface of the body and with white long hairs all over the body. Mature larvae make boat shaped cocoon out of the bark of the host tree or other trees in the vicinity and pupate in groups. Pupal period varies from 15-17 days. The life cycle is completed in little over one month and there are eight to nine generations per year.

Natural enemies Parasites: *Eutachina civiloides* and *Strumia incouspicuella* (Tachinidae) are larval parasitoids); *Sarcophaga* sp. (Tachinidae) is a larval and pupal parasitoid).



▲ **Fig. 65.50** *Eligma narcissus — Top: Larvae feeding on leaves; Bottom: Adult (courtesy: R. V. Varma, Kerala Forest Research Institute, Peechi)*

Predators: *Humbertiella ceylonica* (Mantidae) feeds on pupae and larvae whereas *Panthous bimaculatus* (Reduviidae) is predaceous on larvae.

Pathogens: *Paecilomyces farinosus* and *P. fumosoroseus* infect larvae and pupae.

Control: Spray 0.05 % monocrotophos, quinalphos etc. in nursery. In plantations, insecticidal application is not generally recommended.

8. THE AMERICAN BOLLWORM *Helicoverpa armigera*

The insect has a world-wide distribution. In India it is commonly known as the gram pod borer as it is a serious pest on pulses. This is a polyphagous species which feeds on cotton bolls, sorghum ears, pods of pigeon pea and lablab, safflower, chillies and okra fruits (Fig. 65.51), groundnut, tobacco, *Cicer arietinum* pods, tomato fruits, etc. The larvae feed on leaves and fruiting bodies. As a pod borer the internal contents are completely eaten away resulting in serious loss.

▲ **Fig. 65.51** *Helicoverpa armigera larva feeding of Okra fruit (courtesy: Mitsui Toatsu, Japan)*

Life history: The spherical yellowish eggs are laid singly on tender parts and buds of plants. The incubation period is two to four days. The larvae feed on foliage and later attack the pods or bolls. When fully grown it is greenish with dark broken gray lines along the sides of body and measures about 35 to 45 mm long. Characteristically while feeding, the head will be thrust inside leaving rest of the body outside. Cannibalism among larvae is common. The larval period lasts for 18 to 25 days. It pupates in the soil in an earthen cell and emerges in 6 to 21 days. The moth is large and brown with a V- shaped speck and dull black border on the hindwings.

Host plants: Cotton, sorghum, *Eleusine coracana*, safflower, pigeon pea, *Lablab niger, Cicer arietinum, Phaseolus mungo, P. radiatus*, chillies, groundnut, tobacco, lady's finger, tomato, *Laggera aurita, Momordica charantia*, marigold, chrysanthemum, *Gynandropsis pentaphylla*, calendula, maize, etc.

Control: The preventive measures used for spotted bollworms are applicable for American bollworm also.

9. THE BHALIA LEAF CATERPILLAR *Hypena iconicalis* Walker

This species is distributed in India, Sri Lanka, Myanmar, Java, etc. It was first noticed in Ranchi in 1962 as a serious pest of *Bhalia (Moghania macrophylla)* and since then observed to cause considerable damage to *bhalia* in Uttar Pradesh and Madhya Pradesh. Its other host plants include *Butea frondosa, Dalbergia cephalotes, D. sambuense, D. sissoo, Desmodium gangeticum,* etc.

First instar larvae nibble the lamina of the leaflets making several minute holes; second and third instar larvae make bigger holes in the lamina; and the fourth and fifth instar larvae eat away the whole leaflets except the veins and midribs. Infestation is prevalent during June-October.

Life history: The pre-oviposition period is two to four days and egg laying generally takes place at night. More than 75 per cent eggs are laid singly or in groups of two to four eggs on leaf buds. It also lays the eggs on rachis, axils, petioles and tender leaflets. A female lays 74-339 eggs, the average being 158. The egg is translucent, round with two definite poles, basally more flat, and measures 0.6 mm in diameter. Conspicuous impressions of ridges and furrows across the two poles are differentiated. Each ridge is further characterised by a series of segmental areas demarcated by reddish inter-segmental stripes. The incubation period is three to four days. The larva passes through five larval instars. The full grown larva measures 22-25 mm long, smoky black with dorsal white spots on abdominal segments 1,2,3 and 8, and a broad yellow lateral line along either side of the body at the level of the spiracles. Head is testaceous with large setal spots. Thoracic legs are black, three pairs of prolegs smoky black and anal pair yellowish. The larval period lasts for 6-15 days. Pupation takes place in the soil in a thin silken cocoon a few mm below the soil or sometimes in the folds of the fallen leaves. The pupal period ranges from 7-14 days. There are six generations during July-December and the life cycle from egg to adult is completed in 17-21 days during July-September and 19-33 days during October-December.

Carcelia modicella Wulp, *Sisyropa formosa* Mesnil (Tachinidae), *Scenocharops* sp. and *Eriborus* sp. (Ichneumonidae) are parasitic on the larvae.

10. THE PADDY ARMY WORM *Mythimna separata*

The insect is found in India, Pakistan, Sri Lanka, Myanmar, Thailand, Java, Celebes, Vietnam, Taiwan, the Philippines, Japan, Korea, China, New Guinea, Australia, etc. in the old world.

Outbreak of this army worm occurs after heavy rains and floods. The larvae feed on the leaves leaving the midribs on sugarcane, sorghum, finger-millet, rice, etc. The grass blades are eaten entirely. The immature ears are also damaged by them.

Life history: The eggs are shining white, spherical with fine reticulations. They are laid in rows or in masses of 20 to 76 between overlapping leaf sheaths of sugarcane or on rolled leaves or under leaf bases of rice. The full-grown larva is dirty pale brown or dark with a median dark brown line and two dark brown and one white lateral stripes. The head is greyish-brown.

It pupates in the soil in an earthen cell or sometimes inside leaf sheaths on plants. The moth is pale brown with dark specks; hindwings pale with a brown tinge. The average egg, larval and pupal periods being, respectively 5, 23 and 8 days.

Host plants: Rice, sugarcane, sorghum, *Eleusine coracana, Panicum miliare, Setaria italica*, maize, wheat, oats, pea, grasses, etc.

Crows, sparrow and mynah devour the larvae. *Perisierola* sp. (Bethylidae) is parasitic on larvae.

Control: Spray application of chlorpyrifos 0.02% or cypermethrin 0.025% is suggested.

11. THE MANGO SHOOT WEBBER *Orthaga exvinacea*

This is a pest of importance on mango infesting the shoots to the extent of 35 per cent of trees. The yellowish-green, flat eggs are laid either singly or in groups of 30-60 on upper surface of leaves close to the midrib. The incubation period varies from 2.0 to 3.5 days. There are seven larval instars, the larval period being 26-39 days. The full-grown larva is dark grey with a brown head capsule. A black band across the thorax and several transverses bands on lateral sides are present. The larvae remain inside the leaf webs and feed gregariously on leaf surface scraping the tissues. The infested leaves are webbed together and from third instar feed voraciously on the entire leaf leaving the midrib. Pupation occurs either inside the folded leaves or webbed foliage. The pupa is dark brown and measures 12-15 mm long. The pupal period lasts for 11-18 days. The moth is grey with blackish wings with dark patches. The entire life cycle is completed in 40-63 days. A carabid

Chlaenius quadricolor and the red ant *Oecophylla smaragdina* are predaceous on the larvae. Spray application of cypermethrin 0.025% controls the pest.

12. THE FRUIT SUCKING MOTHS *Othreis fullonica, O. homaena (= O. ancilla), O. fraterna* and *Rhytia hypermenestra* (Figs 65.52 & 53)

The moths emerge in large numbers after rains in July-August when the fruits are half ripe and during nights pierce the ripening fruits with their long sharp proboscis and suck the juice. Thus the moth is directly concerned with damage. In India this attacks all varieties of citrus excepting sour lime, mango, cashew, pomegranate, banana and tomato. The attacked fruits develop a rot round the seat of puncture and drop off prematurely.

▲ **Fig. 65.52** *Fruit sucking moths: Left—Top to bottom: Othreis fullonica (male),O. fullonica (female), O. homaena (female); Right- Top to bottom: Othreis materna (female), O. materna (male), Rhytia hypermenestra (male) (courtesy: M. Swamiappan, Tamil Nadu Agricultural University, Coimbatore)*

▲ **Fig. 65.53** *Top—Larva of Othreis materna on Tinospora cardifolia; Bottom—Larva of O.homaena on Cocculus (ibid)*

Life history: The fairly big-sized, attractively coloured moths lay the eggs singly on tender parts of a wild creeper *Tinospora cardifolia* or on other plants like *Cocculus hirsutus* and *C. pendulus.* The incubation period is three days. The larvae feed on leaves. It is a semilooper, about 50 mm long, velvetty dark, speckled with beautiful and prominent orange, blue and yellow spots. The larval period lasts for about 20 days. It pupates inside the leaf fold and the adult emerges in about nine days.

The larvae are parasitised by *Tetrastichus ophiusae* and *Euplectrus lenocos*.

Control: Systematic destruction of the host plants should be carried out in the vicinity of the orchard. Catching and killing the moths with light torches can be tried. Smoking the orchards during nights scares away the moths. Covering the fruits with polythene or paper bags also affords protection.

13. THE SAFFLOWER CATERPILLAR *Condica capensis*

This is one of the important pests of safflower in India. The larvae in the early stages bite holes in the leaves and they feed voraciously as they grow. Occasionally they also attack the flower heads. It also breeds on *Coreopsis, Blumea*, jute and niger.

The moth is stout with dark brown forewings having a pair of eye-like markings in the centre and the hindwings are light brown. The greenish spherical eggs are laid singly on the leaves and a female lays about 400 eggs. The incubation period is four days. The full-grown larva is smooth, and with head having a network of brown lines, brown body and slightly humped anal segment. It measures about 25 mm. The larval period lasts for about two weeks. It pupates in the soil and the adult emerges in about eight days.

The larvae are parasitised by *Euplectrus euplexiae* (Eulophidae) and *Rhogas percurrens* (Braconidae). Dusting carbaryl 10 % controls the pest.

14. THE LILY MOTH *Polytela gloriosae*

It is distributed in India and Sri Lanka and is a sporadic and specific pest of lilies (*Lilium parvum*) in India. The larvae defoliate the lily plants and cause severe damage.

The moths emerge after the first heavy showers. They mate in tail to tail position. It lays the eggs in July during nights on the apical portion of the undersurface of leaves in clusters of 13 to 42 eggs. A female lays 15 to 45 eggs. The egg is round and dorso-ventrally flattened and yellowish in colour. The incubation period is three to six days. The larval stage lasts for 16 to 20 days. The full-grown larva measures 39 to 42 mm, and has a chocolate brown head and black, white and red mosaic patterns on the body. It pupates in the soil in an earthen cocoon and the adult emerges in 15 to 20 days. The moth has mosaic patterns of red, yellow and black on forewings with a row of regular black and yellow dots along the apical margin. The hindwing is black.

In North India, the first generation takes 31 to 35 days till the end of August and the second generation lasts up to middle of October. The pupae of second generation hibernate and emerge after showers during the rainy season the following year. The insect has two generations in a year.

Spray application of carbaryl 0.05% or cypermethrin 0.025% is suggested.

15. THE PINK BORER *Sesamia inferens* (Fig. 65.54)

The insect is distributed in India, Pakistan, Sri Lanka, Malaysia, the Philippines, Taiwan, China, Indonesia, Myanmar, Japan etc.

The larva bores into the stem and kills the central shoot causing "dead hearts." There may be up to five larvae inside a stem and often a number of plants may be damaged by a single caterpillar. In India it is mainly a pest of finger millet.

The moth is stout, straw coloured with forewings having three small black dots and an intermediate brown stripe. The hindwings and thorax are white. The female lays about 100 yellowish eggs inside the leaf sheath in one to three rows. The incubation period is seven days. The full-grown larva measures 20 to 26 mm and is pale yellow with a purple pink tinge and reddish-brown head. The larval period lasts for 25 to 54 days. It pupates inside the stem and the adult emerges in 8 to 12 days.

▲ **Fig. 65.54** *Larva of Sesamia inferens (courtesy: Mitsui Toatsu, Japan)*

Host plants: Eleusine coracana, Sorghum, maize, rice, wheat, sugarcane, *Pennisetum typhoideum*, etc.

Control: Chemicals suggested under spotted bollworms can be followed.

16. THE RAGI CUTWORM *Spodoptera exigua* (Fig. 65.28)

This is an important polyphagous pest found in India causing serious destruction to lucerne and pulses. It also attacks chillies, safflower, onion, brinjal, tobacco, coriander, cotton, radish, gingelly, cowpea, indigo, castor, finger millet, *Sesbania bispinosa,* etc. In finger millet (ragi) the nursery is primarily attacked during April-July. The larvae defoliate the plants. In the northern part of the country it is a major pest on lucerne and pulses. The moths emerge between 10 PM and 12 AM and copulate in the early hours of morning. Pre-oviposition period is one to two days. The eggs are laid in masses at 9-150 eggs per mass on different parts of plants during nignt time and 66-315 eggs are laid over a period of two to five days. A female has been noticed to lay as many as 1310 eggs. Egg is oval with radiating longitudinal lines iridescent pearlaceous to pink in colour, and measures 0.5 mm. The incubation period is two to five days. There are five larval instars. The full-grown larva is green to brown and measures 22-25 mm long. The larvae hide during day time in the soil and during night feed on leaves and pods. Larval period varies from 9-23 days. The larva pupates in an earthen cell in the soil. The pre-pupal and pupal periods being respectively, 1 and 7-21 days. The pupa is reddish-brown. The moth is greyish to brown in colour, the forewings being mottled grey or brownish with two markings, one light in colour in the center and the other oval and darker near the first one. Hindwing is comparatively paler blending darker near the edges around which there is a light band of cilia. The colour of abdomen is similar to forewings. The pest hibernates as pupa in soil from April to November. There are three generations in a year, being active from November to March.

17. THE TOBACCO CATERPILLAR *Spodoptera litura* (Fig. 65.28 & 55)

It is found in Asia and Australia. In India, though polyphagous, it is considered to be one of the a major pests of tobacco and hence the name "tobacco caterpillar." The caterpillars feed on leaves in the nursery, in the fields, and often cause serious damage; the larvae bore into the fruits of crops like tomato and chillies and spoil them.

The moth is stout, dark with wavy white markings on the forewings and white hindwings, margin having a brown colour. It lays eggs in a mass on the leaves and covers them with brown hairs. The incubation period is four to five days. The full-grown larva is stout, cylindrical, pale greenish-brown with dark markings.

Some have transverse and longitudinal gray and yellow bands and others have rows of dark spots. It measures 35 to 40 mm long. It feeds during night time. It pupates in the soil in an earthen cocoon. The larval period lasts for two to three weeks. Adult emerges in about two weeks. Life cycle occupies 30 to 40 days.

It feeds on tobacco, banana, *Sesbania grandiflorum*, cotton, tomato, castor, groundnut, safflower, sweet potato, *Marsilia*, cabbage, soybean, etc.

Control: Spray application of endosulfan emulsion (30 ml 35EC in 22.75 litres of water) at 30-45 litres / 10 sq. m. area of nursery is recommended for controlling the larvae in tobacco nurseries. Spray application of chlorpyrifos 0.02% is effective against the larvae. The synthetic pyrethroids like deltamethrin at 12.5 to 15 g a.i./ha, cypermethrin at 80 g a.i./ha, and fenvalerate at 100-150 g a.i./ha are also effective. The combinations cypermethrin 50 g + chlorpyrifos 500 g / litre, cypermethrin 30 g + quinalphos 200 g / litre, alphamethrin 10 g + chlorpyrifos 160 g / litre, and deltamethrin 10 g + triazophos 450 g / litre can be used for controlling it on chillies.

▲ **Fig. 65.55** *Larva of Spodoptera litura (ibid)*

18. THE SWARMING CATERPILLAR OR ARMY WORM *Spodoptera mauritia*

This species (Fig. 65.28) is widely distributed and is a pest of some importance on rice in South India. It usually occurs on rice during July to September. In the nursery the seedlings are cut and completely eaten up as though grazed by cattle. In the transplanted crop they strip the plants of their leaves leaving behind leaf midribs. If the outbreak is severe, serious damage may result in heavy loss of crop.

Life history: The adult moth is medium sized, stout, dark brown with a conspicuous spot on forewings. The female lays small spherical eggs in batches of 200 to 300 on various wild grasses and rice, and covers them with greyish hairs. The eggs hatch within a week and the larvae feed on the crop mostly during night.

The early instar caterpillars are green and as they grow become dark brown or grayish green. Often it exhibits colour variations. The larva becomes full-grown in 20 to 25 days. It measures 35 to 40 mm long and is smooth, cylindrical and dark to pale green with dull dorsal and subdorsal stripes. It pupates in the soil in an earthen cocoon. The moth emerges in 10 to 15 days. The life cycle lasts for 30 to 40 days. Besides rice it breeds on a variety of grasses.

The larvae are parasitised by the tachinid flies. *Sturmia bimaculata, Tachina fallax*, *Actia aegyptia* and *Isomera rufifrons.*

Control: In nurseries and small fields flooding brings out the larvae to the surface which are destroyed by birds. Ducks, if let into the field, will feed on the caterpillars. Spray application of chlorpyrifos or endosulfan or monocrotophos at 0.5 kg a.i./ha is suggested.

19. THE CABBAGE GREEN SEMILOOPER *Trichoplusia ni*

This is a serious pest of cabbage in the USA. It is widely distributed and occurs throughout India. In South India it inflicts severe damage to cabbage in the plains.

The insect is found in large numbers from September to April. The caterpillars eat away the leaves of cabbage plants in the nursery and in the fields. The veins and midribs of leaves alone will remain on the plants. In severe cases the crop is ploughed in. Its infestation causes reduction in yield by 30 to 60 %.

The moth is stout, brown with light wavy markings and a more slender mark on forewings. The female moth lays greenish-white, spherical sculptured eggs singly on the undersurface of leaves. The caterpillar is slender, attenuated anteriorly and measures 38 mm when full-grown. It is green with light wavy white lines and a broader lateral stripe. It pupates in a thin transparent cocoon on the undersurface of leaves. Life cycle extends to about a month.

In India it feeds on cabbage, cauliflower, safflower, opium poppy, nettle, *Solanum* sp., *Helianthus annuus*, *Antirrhinum* and tomato.

Spray application of cypermethrin 0.025% or fenvalerate 0.025% is suggested.

Family Lymantriidae [Liparidae; Ocneriidae] (tussock moths)

The insects are medium-sized moths, the males having bipectinate antennae. Ocelli are absent. Tufts of hairs are seen at the anal end in the female and the eggs are covered with these anal hairs. The larvae are densely hairy and often have compact tufts of hairs on the dorsal aspect of certain segments. On the sixth and seventh abdominal segments osmeteria are often seen. The larvae of *Euproctis* possess urticating hairs on their body. Pupation takes place in a silken cocoon on plants. In some cases the sexes can be separated in larval and pupal stages. There is extreme sexual dimorphism in a few cases. The females of *Orgyia* possess only vestigial wings and the males are winged. In *Perina nuda* the female possesses creamy-white wings, the male being smaller and having transparent wings except at the base, which is covered with brown scales.

In America larvae of the tussock moths and the gypsy and brown-tail moths are considered to be potential pests of forest and shade trees. The tussock moth *Orgyia leucostigma* is a native species. The gypsy moth *Porthetria dispar* and the brown-tail moth *Nygmia phaerrhoea* were introduced from Europe. In the forests of Germany the nun moth *Lymantria monacha* is often a serious pest. In India the larvae of a number of species of lymantriids are pests of crops. The common species are: *Euproctis fraterna, E. lunasta* on Acacia trees, *E. lutifascia* on cardamom, *Psalis pennatula* on rice, *Porthesia scintillans*, *Dasychira horsefieldi* on tea, *Dasychira moerens* and *D. mendosa* on rose, *Orgyia postica* on castor, *Perina nuda* on *Ficus* and *Laelia adalia* on guinea grass.

1. THE CASTOR TUSSOCK CATERPILLAR *Orgyia postica*

The distribution of this insect extends to Sri Formosa, Lanka, Myanmar, Borneo, Java, New Guinea and India.

▲ **Fig. 65.56** *Orgyia postica—Adult apterous female and winged male (T.V.R. Ayyar, 1940)*

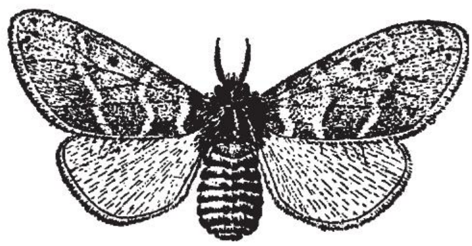
It is a polyphagous species and feeds on castor, rose, *Erythrina indica*, *E. lithosperma* and geranium.

The moths emerge during night or in the early hours of morning. The female is sluggish and cling to the cocoon. Soon after mating it lays eggs on the surface of the cocoon itself in an irregular mass. A female lays up to 656 eggs, the average being 350. The eggs are cream coloured and subspherical. The incubation period is seven days. The male larva undergoes four moults whereas female undergoes five moults. The full grown larva has a brown head, a pair of long pencil-like hair pointing forwards from the prothorax, lateral tufts of yellowish setae in the first two abdominal segments, yellowish tufts of hairs dorsally on the first four abdominal segments, and long brown hairs dorsally on the eighth abdominal segment. The female larva is robust and measures 27 mm as against male larva, which measures 19 mm and shows a deeper shade of yellow in the general body colouration including the tussock on the first four abdominal segments. The larval stage lasts for 16 days in males and 17 days in females. The larva pupates in a transparent cocoon formed inside leaf fold or on twigs occasionally. Pupal period is seven days in males and four days in females. The female pupa is bigger than male. The wings are brown in male whereas the female moth possesses only vestigial wings. The total life cycle lasts for 27 to 33 days.

Apanteles colemani is parasitic on the larva in India.

2. THE CASTOR HAIRY CATERPILLAR *Euproctis fraterna*

Euproctis fraterna (Fig. 65.57) is a sporadic pest of castor. The larvae are defoliators of castor, cotton, pomegranate, rose, mango, pigeon pea, pear, *Tylophora asthmatica*, etc.



▲ **Fig. 65.57** *Euproctis fraterna (T.B. Fletcher, 1914)*

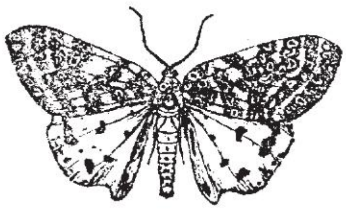
The eggs are flat, circular, yellow and are laid in masses covered with yellow hairs on the undersurface of leaves. The early instar larvae have whitish hairs and feed gregariously. The full-grown larva has a red head, reddish brown body with white hairs surrounding the head and a single long tuft in the head and another in the anal region. It pupates in a cocoon of hairs on the leaves or on branches. The moth is yellow with pale transverse lines on the forewings. The life cycle lasts 45 to 57 days, the egg, larval and pupal periods respectively being 5 to 9, 29 to 35 and 10 to 12 days.

3. THE HAIRY CATERPILAR *Porthesia scintillans*

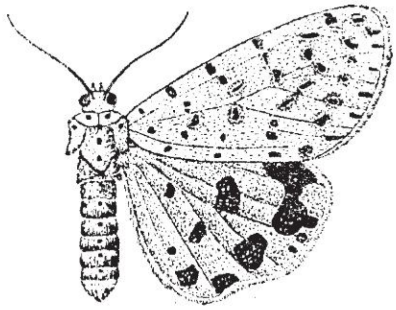
Porthesia scintillans feeds on rose, castor, cotton, pigeon-pea, mango, linseed, gogu (*Hibiscus sabdariffa*), sunnhemp, *Loranthus, Vigna catjang*, *Sesamum indicum*, pumpkin, pomegranate, *Ficus bengalensis. Acacia arabica, Cassia fistula*, apple, jute, etc. The larva has yellowish-brown head and yellow dorsal stripe with a mid-dorsal red stripe. There are tufts of black hairs dorsally on the first three abdominal segments. The moth is yellowish with a reddish line and spots on the edges. Life cycle is similar to *E. fraterna.*

Family Hypsidae

The moths have a well-developed proboscis. The larvae have long, dense hairs and pupate in a very light silken cocoon. The insects are found in Africa, the Orient and Australia. The common Indian species are: *Hypsa complana, H. alciphron, H. ficus, Argina argus, A. syringa* (Fig. 65.58) and *A. cribraria* (Fig. 65.59).



▲ **Fig. 65.58** *Argina syringa (ibid)*



▲ **Fig. 65.59** *Argina cribraria (ibid)*

THE SUNNHEMP HYPSID *Argina cribraria*

The insect is found in India, Sri Lanka, China, Mauritius, Myanmar and New Guinea.

In South India it is a pest of *Crotalaria juncea* (sunnhemp), which is grown as a green manure crop. The larvae defoliate the plants and also bore into flower buds and pods. Apart from sunnhemp it also infests *Crotalaria serica, C. salitana, C. retusa, C. anagyroides* and *Calapagonium corensis.*

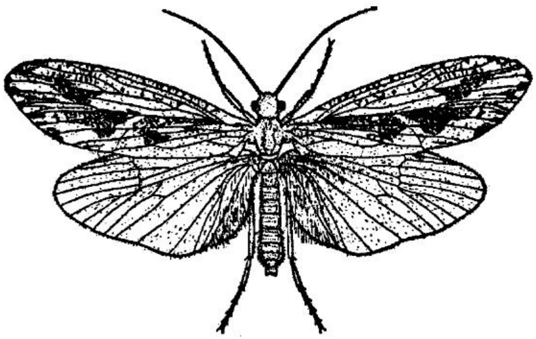
The yellowish eggs are laid in small clusters on the undersurface of leaves. The incubation period is two to three days. The larva passes through five instars and at its sixth moult pupates. The larval period is 18 to 21 days. It pupates on the plant or on the surface of the soil. The adult emerges in six to seven days. The moth is medium-sized with orange yellow head, thorax and forewings and orange coloured hindwings and with black spots on both pairs of wings. The total life cycle lasts from 26 to 31 days.

◆ Chapter 66

Order Trichoptera

CADDISFLIES

The Trichioptera include the "case worms' or caddisflies (Fig. 66.1), which are moth-like, mostly nocturnal insects with weak powers of flight. The adults frequent the vicinity of water bodies, and the case-bearing larvae and pupae are aquatic. The head is usually small, with moderately large widely separated compound eyes and three ocelli. The antennae are very long, setaceous and multi-articulate, held in front of the head when at



▲ **Fig. 66.1** *An adult trichopteran or caddisfly (B.D. Moreton)*

rest. The vestigial mouthparts are of the biting or chewing type, the mandibles reduced or absent and the labrum short or elongate. The maxillae are small, reduced, often associated with the labium; palps four- to six-segmented. Labium well developed, with a well-developed mentum, short prementum, a median glossa and a three-segmented labial palp. The hypopharynx is well developed. In some genera both labrum and labium are elongated to form a rostrum.

Of the thoracic segments, the prothorax is the shortest and mesothorax the largest. The long and slender legs bear strong coxae and both the meso and metathoracic coxae bear a meron. The tibiae have well developed spur and spines and the five-segmented tarsi bear the claws, and the pulvilli. Though a few genera are apterous or brachypterous, the majority of Trichoptera bear two pairs of large hairy membranous wings, the hindwings generally larger. The degree of hairyness varies from the fully clothed wings to a general absence of hairs and appear covered with fine scattered scales. A fairly complete set of longitudinal veins are distinct, but the cross veins are reduced in number. A semi-transparent whitish spot called the thyridium is often very characteristic of both pairs of wings, near the fork of R_4-R_5.

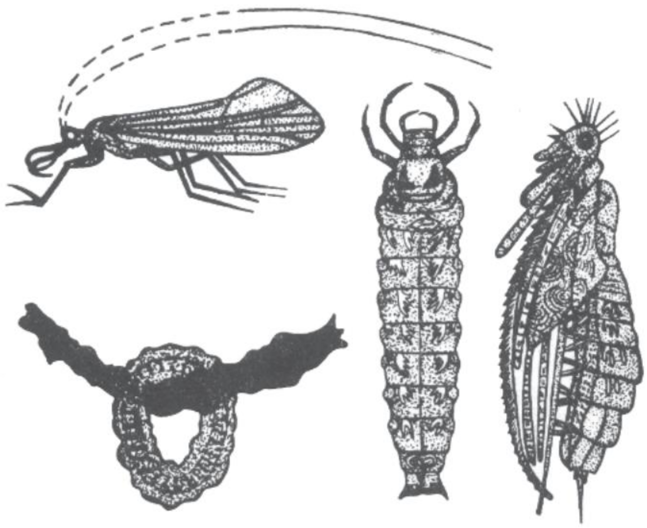
A characteristic feature of importance is the distinct M_4 of the forewing, which unlike in Lepidoptera is not fused with Cu. The jugum and anal fold are present in some, vestigial or absent in others. In some genera (*Rhyacophila*) the jugal lobe of the forewing rests on the costa of the hind wing. In most forms, the wing coupling is of the amplexiform type, the fold on the anal area of the forewing holding on to the costa of the hindwing mostly by a row of costal hooks on the hindwing.

The abdomen is ten-segmented, the terminal segments in the female sometimes being retractile and tubular, serving as an ovipositor.

The alimentary canal is short, with paired tubular salivary glands and six malpighian tubules. A crop is distinct, leading into a tubular, slightly coiled intestine and a short hind intestine bearing an expanded rectal chamber with 6 to 30 rectal papillae. In the nervous system the ventral nerve cord bears three thoracic and seven abdominal ganglia. Numerous polytrophic ovarioles are present in the ovaries, with a distinct bursa copulatrix in the eighth segment. The testes are paired, ovoid structures and accessory glands open into the vasa deferentia. In some, a distinct aedeagus and parameres are present in the male genitalia. The larvae (Fig. 66.2) abound in lakes and streams and as the case making habit is developed to a large degree they are called caseworms or caddisflies. The cases are of varied sizes and shapes, straight to coiled and with foreign materials utilised in their construction, such as small stones, bits of snail shells, small sticks and twigs, bits of leaves, sand grains, etc.

The egg laying capacity of females varies from 300 to 1000 eggs. They are laid on stones or other submerged objects, in strings or sometimes in gelatinous masses. The larvae are rarely terrestrial as in *Enoicyla* living in mosses. The larvae of *Rhyacophila* are freeliving and are not confined within cases. The larvae are predatory, feeding on small insects or other organisms. In some, the larvae weave a fine net or shelter to trap small organisms, as in *Hydropsyche*.

The larvae possess well developed, sclerotised head, more strongly developed mouthparts, with short, well developed legs adapted for clinging, crawling or swimming. Only the well sclerotised head, legs and the anterior parts are thrust out of the case while moving. Paired prolegs or caudal hooks are present in the abdomen to help in anchoring or fixing the body to the case. Filamentous tracheal gills and rarely rectal blood gills are rarely present. The first abdominal segment mostly bears three prominent retractile papillae, one dorsal and two lateral. Tracheal gills are arranged in groups, dorsal, lateral and ventral series. Gills are absent in the first instar and develop only later. A tuft of anal gills is present in some. Many case-bearing larvae possess longitudinal cuticular folds on either side of the abdomen, set with fine hairs known as the lateral line. Thoracic glands, often branched tubes (also called Bibron's glands), which are present in many larvae, are regarded as accessory organs of excretion.



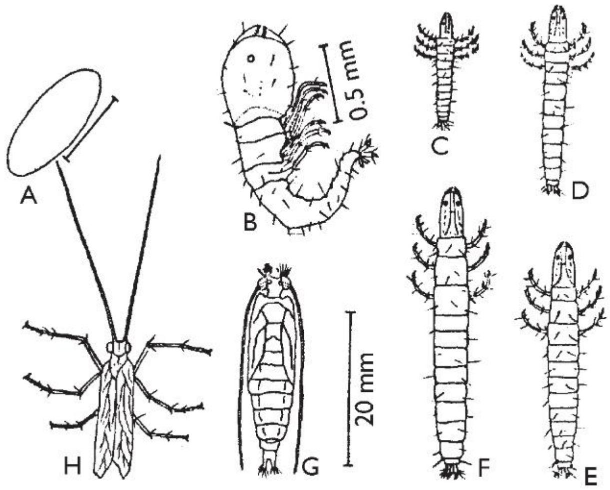
▲ **Fig. 66.2** *Egg mass, larva, pupa and adult of a caddisfly (from V.A. Little, General and Applied Entomology, Harper & Row)*

Silk glands are well developed and before pupation the larva spins a cocoon, which is mostly ovoid and made of silk, sand and debris and attached to stones, logs, etc. The pupae develop in the cocoon and they possess unusually strong mandibles, serving to cut its way out. The pupae swim across to the surface, crawl over to a log or stone and transforms into the adult.

Two main types of trichopterous larvae are recognised–the campodeoid type with a compressed body not inclined at an angle, not making cases, without abdominal papillae and rarely with rectal gill (families: Rhyacophilidae, Hydroptilidae, Polycentropidae, Psychomyiidae, Hydropsychidae, etc.); and the eruciform type, with the head inclined at a distinct angle, with portable cases and with tracheal gills (families: Limnephilidae, Sericostomatidae, Phryganeidae, Leptoceridae, etc.).

Some Trichoptera have been reported as minor pests of rice. The rice caddisfly *Setodes argentatus* from Japan, feed on the roots and basal portion of rice stem. The egg masses laid on the surface of water, sink to the bottom as a gelatinous mass. The larva fixes its case to the submerged pebbles by silk spun by it. *Triaenodes bicolor* known from Italy, causes damage by cutting leaves of young rice plants, for constructing larval cases. *Oecetis nigropunctata, Limnephilus amurentis* and *L. correptus* occur in eastern Siberia, China, Korea, Japan and cause minor damage.

The net spinning caddisfly *Stenopsyche haimavatika S*chmid (Stenopsychidae) (Fig. 66.3):



▲ **Fig. 66.3** *Life history of the net spinning caddisfly, Stenopsyche haimavatika A. Egg, B. First instar naiad, C. Second instar, D. Third instar, E. Fourth instar, F. Fifth instar, G. Pupa, H. Adult. (R.S. Bisht & Manmohan, Indian J. entomol. 63:1, 2001))*

It is a dominant species found in almost all the snow and spring fed streams of Garhwal (500 to 2800 m above sea level.) and its larvae serve as fish food. It is a bi-voltine species breeding twice a year, one during September-October and the other from April-June. After copulation the female sits over a partially submerged stone, rests for one to two minutes, then dives under water and reaches the undersurface of a stone, and lays in two to three minutes 540 to 953 eggs in irregular masses cemented together. This suggests saxicoline breeding habit. The yellowish-white egg measures 0.60 to 0.67 mm long. The incubation period ranges form 18 to 32 days. There are five larval stages and the total larval period varies from 106 to 143 days. The larvae excepting the first instar construct the protective cases. The cases are made of gravel and stones cemented together and lined throughout with the silken thread secreted by salivary glands. These cases are laid on interstices of stones. All the larval instars are more or less alike except the first instar. The first instar is herbivorous principally feeding on algae and is neustonic. But the other instars are omnivorous, benthic, and saxiclone. The fifth instar larva plugs the anterior and posterior opening of the case, stops feeding and pupates inside the dome-shaped case. The adult from the light green pupa emerges after a pupal period ranging from 21 to 26 days. The newly emerged adult climbs up a partially submerged stone or floating object, rests for one to three hours and then leads a short terrestrial life.

Stenopsyche kodaikanalensis Swegman & Coffiman has been reported from South India.

◆ Chapter 67

Order Hymenoptera

Ants, Bees, Braconids, Chalcids, Ichneumonids, Sawflies, Wasps, etc.

This is a large order comprising of a great many insects, which are beneficial to man. Most of them are parasites or predators on other insects and the part played by these insects in biological control of notorious and introduced pests of crops needs no emphasis. The bees are well known for their role in pollination of plants, and in addition to this honeybees yield honey and wax. Hymenopterous insects are highly specialised in structure, surpassed only by Diptera. These insects show a great diversity of habits and their behaviour is very complex. Individuals live together in societies culminating in social organisation as in wasps, bees and ants. For a detailed knowledge of social behaviour in hymenopterous insects, reference may be made to an earlier chapter on the topic.

Though these insects are remarkably highly evolved in parasitism, those belonging to Symphyta are phytophagous, excepting *Orussus,* which is parasitic in its larval stage. Among the Apocrita, the Cynipoidea, whole of Ichneumonidae and Proctotrupoidea and most of the Chalcidoidea are parasitic. The phenomenon of polyembryony is evident in Chalcidoidea and Proctotrupoidea. Varied effects are produced by hymenopterous parasites on their hosts. The bi-voltine chalcid parasites of coccids in their first generation parasitise the young forms of coccids, which get killed. The parasites of second generation attack the older forms of its host and the adult females of the coccid lay some or all eggs before being overcome by the parasite. In ants malformation or abortion of certain parts occurs due to the ectoparasite, *Orasema*, and such individuals do not become adults. The development of secondary sexual characters is inhibited by dryinid parasites in Homoptera.

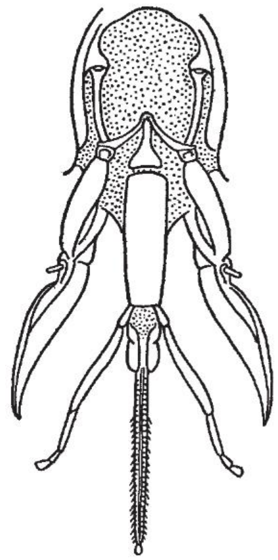
Parthenogenesis is evident in a number of cases, especially the honeybees. In honeybees and the wasp, *Vespa*, the unfertilised eggs give rise to males. In ants, the unfertilised eggs give rise to males or worker ants of both sexes develop from the unfertilised eggs laid by worker ants. Individuals of both sexes may be produced parthenogenetically as in Cynipidae wherein this phenomenon is alternated with sexual reproduction. In some cases only females are produced parthenogenetically throughout their development and males may be either absent or rare. In Tenthredinidae certain species produce only males parthenogenetically whereas the others may give rise to only females, or both sexes may be produced.

Morphology

The head is variable in form and often extremely mobile. It is free from the thorax. The clypeus and labrum are distinct and the epipharynx well developed which in higher forms is trilobed, the median lobe being pointed or projected. The compound eyes are large and in males are holoptic. The eyes are atrophied in certain species of ants of the genera *Dorylus* and *Eciton*, or they may be found reduced to a single facet on either side in a few other species of *Eciton*. In most cases the ocelli are three in number and ocelli are lacking in the workers of many ants of Bombicinae. The antennae exhibit variation in form, number of segments and location. They are longer in males and pronounced sexual dimorphism is quite evident in the Proctotrupoidea and Chalcidoidea and in the males they are either filiform, clavate, pectinate, branched or verticillate. The number of antennal segments are variable: three in the sawfly *Arge*, four in ants, 14 to 70 in Ichneumonoidea, 12 in male and 13 in female of Sphecoidea, Vespoidea and Apoidea. The antennae are elbowed distinctly in the queen and worker ants than in males.

The mouthparts (Fig. 67.1) show variations in the form of the mandibles and structure of the tongue, which are of some importance in classification. The Symphyta possess generalised orthopterous type of biting mouthparts, whereas the bees have highly modified sucking type. The well-developed mandibles are used for cutting through the cocoons at the time of emergence in parasitic forms, or for gathering material and nest building in Sphecoidea, Vespoidea and Apoidea. Only in predaceous Tenthredinidae they are trophic. The mouthparts of a typical sawfly comprise of well-developed dentate mandibles, maxillae with six-segmented palpi and labium with prementum, submentum, a median glossa, lateral paraglossae and four-segmented palpi. In *Vespula* the labium has a large prementum bearing elongated paraglossae, a wide-bilobed glossa and four-segmented slender palpi, and the mouthparts are thus adapted for biting, mastication and licking. Among parasitic Chalcidoidea reduction in the number of labial and maxillary palpi is evident.

The maxilla is often single lobed and the glossa forms the broadened ligula, the paraglossae being either wanting or vestigial. In the higher members the glossa becomes progressively lengthened in accordance with feeding and collection of nectar results in the formation of a proboscis. In *Apis* the glossa forms the sucking organ with a small flabellum at its apex.



▲ **Fig. 67.1** Apis *sp. worker, labium and maxillae with attachment to head (Snodgrass, 1935)*

The wings are highly specialised and membranous. The venation is variable and two basic terminologies, viz. an old system and the Comstock system modified by Ross are in use. Among Apocrita, reduction and fusion of veins are noticed. In the Chalcidoidea and certain Evaniidae the hindwing is devoid of veins and the forewing possesses a single compound vein. Both pairs of wings may be veinless in Platygasteridae. The posterior margin of forewing has a fold, which gets interlocked with the hooks or hamuli present along the costal margin of the corresponding hindwing and thus they are held together. The hooks may be reduced to a small group of two or three as in Chalcidae or may be completely absent as in Mymaridae.

Apterous forms occur among worker ants and occasionally in males and in many Agaonidae. The females are apterous in Mutillidae, Thynninae and Myrmosinae. In Proctotrupoidea, Braconidae and certain Ichneumonidae frequently wingless females are present. In the Diapriid *Platymischus* and certain ichneumonids of the subfamily Cryptinae both sexes are apterous.

The leg has the coxa, trochanter, femur, tibia and generally a five-segmented tarsus terminating in an arolium and two claws. In all parasitic forms excepting the Pelecinidae there are two segments in the trochanter and the second segment, called as trochantellus, belongs to the femur. In the Apocrita a knife-like spur or calcar present at the apex of foretibia fits against a semicircular cavity of the basitarsus provided with comb-like fine teeth and the antenna is trimmed by passing through the cavity. In Sphecoidea and solitary wasps, the legs are adapted for digging. In the higher forms of bees (Apoidea) the first tarsal segment of hindleg is enlarged and its flattened inner aspect has several rows of short stiff spines, which are useful in brushing and gathering pollen from its body. Further, the enlarged tibia of the hindleg may have either a large pollen brush or scopa, or the pollen basket or corbicula.

The pronotum and certain mesothoracic sclerites and sutures are of some importance in the taxonomy of Hymenoptera. The pronotum laterally appears to be more or less triangular, extending to the base of forewing as in Cynipoidea, Ichneumonoidea, Proctotrupoidea, Vespoidea, most Scolioidea and some Bethyloidea. It may be somewhat collar-like not extending to the base of forewing and without a rounded lobe on each side as in Chalcidoidea and some Bethyloidea, or may bear a rounded lobe on each side as in the Sphecoidea and Apoidea. In the Chalcidoidea laterally on the thorax a prepectus is present. Parapsidal sutures or notauli may be present or absent, based on which related families can be separated.

The characteristic feature in Hymenoptera is the fusion of the first abdominal segment with the metathorax and this segment is known as propodeum. The propodeum in Symphyta appears to be part of the abdominal segments, but it is specialised in the Apocrita in which it gets incorporated in the metathoracic segment itself and the first pair of abdominal spiracles can be easily made out on this. The region behind the propodeum is the gaster having the maximum of nine visible segments in Tenthredinidae, and only six visible segments in female and seven or eight in male in higher groups. Pygostyles or small lateral setigerous processes are borne on the ninth gastral tergite in a number of groups. In Apocrita the second abdominal segment is wholly or partially constricted and is known as petiole or pedicel. In some Apidae pollen brush or scopa occurs ventrally. The ovipositor is variously modified for purposes of sawing, piercing, boring or stinging. It is reduced in some groups of ants. The ovipositor is made up of three pairs of valvifers. The first pair arises from the eighth sternite to which are attached the long valvulae. These form the saw in Symphyta, the lancets of the sting in Aculeata and the ovipositor in parasitic forms. The valvulae of the first pair are enclosed in an immovable sheath formed by the fusion of the valvulae of the second pair of valvifers arising from the sternits of the ninth segment. The first valvulae move in and out of the sheath freely and the terebra is formed of these two pairs of valvulae. The second valvulae may be serrated as in sawflies or barbed as in bees (*Apis*). From the posterior end of the second pair of valvifers arise the third pair of valvulae. The ovipositor remains without being withdrawn into the body and issues from the abdomen anterior to the apex in Ichneumonoidea, Cynipoidea and Chalcidoidea, whereas in most of the other Apocrita it is withdrawn into the body. In the stinging forms there is a large poison sac containing the secretion of a pair of filiform acid glands, which open into it either individually or by a common duct. The important constituents of the secretion are a protein and certain enzymes; the latter releases histamine when it acts on the tissues of the victim and thus produces many symptoms. Formic acid is the chief constituent in the case of Formica and its allies. The venom component of the workers of the fire ant *Solenopsis saevissima* is a piperidine alkaloid and has been named as solenopsin A.

In the male the genitalia lie above the ninth abdominal sternite, which is concealed. The genitalia consist of a basal ring, a pair of two-segmented forceps having a plate known as volsella attached to the inner edge and two central penis valves, which form the intromittent organ.

Anatomy

The mouth cavity leads into the pharynx and serves as an organ of suction. In the social Hymenoptera a spheroidal infrabuccal sac wrapped in a white membrane is present below the anterior part of the pharynx. The sac opens into the mouth cavity through a short narrow canal. The fine dust particles from the body surface or strained from the liquid are collected in the sac and no enzymes are secreted by the sac. The pharynx is followed by a long narrow tubular oesophagus, which among Aculeata forms a dilated thin-walled crop or honey stomach in the anterior portion of the abdomen. The liquid imbibed is stored and regurgitated when necessary. Between the crop and the ventriculus lies a constricted proventriculus, which has a valve at its posterior end. Pumping of food from the crop into the ventriculus and prevention of regurgitation when the valves are closed, are the functions apparently served by the proventriculus. The ventriculus or stomach may be a U-shaped loop occupying the largest portion of the alimentary canal as in *Apis* and *Vespula*, or may be a small elliptical chamber as in Formicoidea, Sphecoidea and Parasitica or rarely atrophied as in the shortlived female of *Doryctes.* A peritrophic membrane is present. The ventriculus is followed by the short tubular ileum which may be long in *Apis*, and leads to the enlarged rectum having rectal papillae. The number of rectal papillae are three in ants, four in *Doryctes* and six in *Apis* and most other Hymenoptera. The malpighian tubes open separately into the ileum and are extremely variable in number. Often they occur in bundles having a number of tubuli.

In the bee there are two pairs of salivary glands, viz. the cephalic salivary glands and the thoracic salivary glands, which open on the hypopharynx by the common duct. In addition, a mass of gland cells are situated just above the ocelli in drones and queens. A pair of lateral pharyngeal glands occur in workers and these glands are rudimentary or wanting in the queen and drone respectively. These glands are the source of the royal jelly fed to the larval and adult queens and drones. The ventral pharyngeal gland opens into the floor of the pharynx. A sac-like mandibular gland is well developed in the queen than in the worker and poorly developed in the drone. In the worker of *Apis* and also in *Bombus* and *Vespa* an internal mandibular gland opens near the posterior inner edge of the mandible.

The heart is usually composed of four or five chambers; in *Apis* they are seen in the third to sixth abdominal segments and in ants in the fourth to eighth abdominal segments.

The nervous system in the Tenthredinidae comprises of three thoracic and nine abdominal ganglia. Most species of Apocrita have three thoracic ganglia and Crabroninae and Apoidea have two; the second being formed of meso- and metathoracic and one or more of the abdominal ganglia. The second pair innervates the meso- and metathoracic legs, the wings, and the first two abdominal segments. The centres of abdominal ganglia are six in number in many Ichneumonoidea, Formicoidea and a few others; fewer in most other Apocrita; two as in *Cynips quercusfolii* or single as in certain chalcids. The females of many Aculeata have the last two abdominal ganglia more or less fused. In *Megachile* and *Mutilla europaea* the female has five abdominal ganglia as against four in the male. Six ganglia are seen in the female and worker and five in the male of *Bombus*. In *Vespula* the male and female have six ganglia as against five in the worker. The female of *Blastophaga* has two abdominal ganglia, which in the male are fused into a single centre.

The male reproductive system: In Symphyta, *Apis* and *Bombus* the testes are separate. They are fused together in other Hymenoptera whereas in *Vespula* they are in close contact. Each testis contains 250 to 300 follicles (*Vespula, Bombus*, *Apis*) or much less numerous follicles (ants) or three in other Hymenoptera. The vasa deferentia may be voluminous (*Vespula* and *Apis*) or tubular and convoluted (*Athalia, Cimbex* and *Bombus*). A pair of large sac-like accessory glands join the two ejaculatory ducts or may open into a common ejaculatory duct (*Apis*).

The female reproductive system: Each ovary consists of a variable number of polytrophic ovarioles which are numerous in Apis, 1 to about 250 in ants, 130 to 182 in *Blastophaga*, 20 to 30 in *Cimbex*, 5 in *Aphelinus*, 4 in other chalcids and the Icheumonoidea and 2 in *Doryctes*. Though ovarioles are wanting in *Aphidius*, the follicles are enclosed in a sac-like membrane. The oviducts join to form the vagina. The posterior dilation of the vagina forms the bursa copulatrix in *Apis*. A spermatheca is present. A pair of colleterial glands may open into a median reservoir as in *Cimbex* or into the duct of the spermatheca as in *Apis*.

Egg

The egg is ovoid or sausage-shaped. It may have a pedicel arising from either pole of the egg in parasitic groups such as Cynipoidea, Proctotrupoidea and Chalcidoidea.

Larva

A typical hymenopterous larva has a head, three thoracic and nine to ten abdominal segments, and a peripneustic or holopneustic tracheal system in most cases throughout the larval stage or in its later instars. In the Symphyta the larva is very characteristic in having biting type of mouthparts, six or eight pairs of prolegs and a peripneustic or holopneustic tracheal system with nine to ten pairs of spiracles. The larvae are phytophagous and in stem or wood boring species the prolegs are absent and the thoracic legs are much reduced.

The larvae of Apocrita are apodous, maggot-like in form with strongly sclerotised head, which in parasitic forms is reduced to a great extent and sunk into the prothorax. The special sensory organs are degenerated. Ocelli are absent and the antennae are reduced or atrophied. The mandibles are variously modified: sickle shaped, dentate or simple pointed spines with broad flattened bases. The labrum, maxillae and labium are fleshy lobes, the palpi being absent or reduced to small papillae. A holopneustic tracheal system with ten pairs of spiracles is noticed in Aculeata whereas in Parasitica depending upon the mode of life variations occur. A peripneustic system is seen in ectoparasitic larvae, the number of spiracles being nine pairs is typical. The larvae are apneustic in endoparasitic forms in the early stage of development when they are haemophagous. Later they become carnivorous on their hosts and usually nine pairs of spiracles may be seen in the last larval instar. Hypermetamorphosis occurs among many parasitic insects and in addition to the usual type several larval forms of primary larvae are recognised.

a. Planidium as in perilampids, an active larva with spine-like locomotor processes on body segments.
b. Caudate type as in ichneumonids and braconids, vermiform and bearing a caudal process.
c. Cyclopoid or naupliform as in some Proctotrupoidea, with a large swollen cephalothorax, strong mandibles and a caudal process.
d. Teleaform type as in many chalcids with head and prominently hooked, with a caudal process at the hindend and with girdles of setae and body segments.
e. Vesicle bearing type as in *Apanteles* and *Microgaster*, with a prominent anal vesicle.
f. Eucoiliform with a long curved caudal process and with three pairs of long thoracic appendages.
g. Polypod type with 8 to 12 trunk appendages.

Pupa

A prepupal stage occurs in hymenopterous insects. After the last larval moult the prepupa becomes the pupa. The pupa is of exarate type and is enclosed in a cocoon in almost all cases excepting those of Cynipidae and Chaicidoidea. A cocoon is also wanting in bees and ants.

Classification

Order Hymenoptera is divided into two suborders, viz. the Symphyta and the Apocrita. In Apocrita two main divisions, viz. Aculeata or stinging forms and the Parasitica or forms parasitic on other insects, are recognised. However, many exceptions are noticed in these two divisions. Many Aculeata are parasitic on other insects whereas a number of species of Parasitica are phytophagous, and hence no clear-cut distinction can be made between these two divisions.

SUBORDER SYMPHYTA (CHALASTOGASTRA)

The primitive forms of Hymenoptera are included under this suborder. These insects are characterised by the abdomen being broadly joined to the thorax with no marked constriction between the first and second abdominal segments. The legs have two-segmented trochanters. Almost all species are phytophagous and have the ovipositor modified for sawing or boring. The larvae of all, excepting those of *Orussus*, possess thoracic and generally six or more pairs of abdominal legs without crochets.

SUPERFAMILY XYELOIDEA

This includes a single family Xyelidae. The insects are medium-sized to small, with the most generalised type of venation and three marginal cells in the wings. The antennae are characteristic in having greatly elongated third antennal segment followed by a flagellum. The larvae have limbs on all abdominal segments. A well-developed ovipositor is present in adults. This family includes the genera *Xyela* and *Macroxyela*. The larvae of *Xyela julii* feed in the staminate flowers of pine and the adults visit the flowers of *Betula*.

SUPERFAMILY MEGALODONTOIDEA

Family Pamphiliidae

These insects are commonly called as web-spinning and leaf-rolling sawflies. They are stout-bodied insects with a simple antennal flagellum and a short ovipositor. The larvae live in rolled leaves or leaf webs and are devoid of abdominal limbs. *Neurotoma inconspicua* is a webber on plum and *Pamphilius persicum* is a leaf roller on peach.

Family Megalodontidae

The adults possess flabellate antennae and the mouthparts are as long as the head capsule. The larvae web the leaves of plants.

Superfamily SIRICOIDEA

This contains three families, viz. Xiphydriidae, Syntexidae and Siricidae, of which the last named family is important.

Family Siricidae (wood-wasps or horn-tails)

The insects are fairly large and conspicuously coloured with black and yellow or metallic blue. On the last abdominal tergite a horny spear-like plate is seen in both sexes of the insect. The female has a long, strong ovipositor with which it bores into the woody plants and trees and lays the eggs singly in each hole. The larva burrows into the wood and pupates in a silken cocoon with gnawed wood adhering to it. The larva has a horny process on the last abdominal segment, which aids in locomotion. The life cycle may occupy a fairly long period, i.e. about two years. *Uroceras gigas* in British Isles attacks Pinaceae. Species of *Tremex, Sirex* and *Paururus* are met with in India on forest trees in the hills. The common species observed is *Sirex imperialis.*

Superfamily ORUSSOIDEA (Egrasitic Wood Wasps)

This includes a single family Orussidae. The wing venation is reduced and hindwings are without closed submarginal cells. The insects are very small and their apodous larvae are ectoparasitic on larvae of wood boring Buprestidae.

Superfamily CEPHOIDEA

This includes a single family Cephidae, members of which are called stem sawflies. The insects are slender, compressed sawflies, mostly black or darkly coloured with or without narrow, yellow bands. The prothorax is large and articulates freely with the following segment. The apodous larvae bore into stems of grasses, berries, etc. The larvae may sometimes have three pairs of reduced tubercle-like thoracic legs. *Cephus cinctus* and *C. pygmaeus* are the wheat stem sawflies in the USA.

Superfamily TENTHREDINOIDEA

Family Argidae

Small to medium-sized sawflies with characteristic antennae. The last antennal segment is U-shaped and Y-shaped in a few cases.

Family Blasticotomidae

The larva is devoid of abdominal legs. The stems of ferns are bored by the larvae.

Family **Cimbicidae**

The insects are large, stout, bumble bee-like in appearance and possess clubbed antennae. The larvae are characteristic in remaining partly curled up and covered with waxy powder.

Family Diprionidae

These are known as conifer sawflies and are medium-sized with serrate antennae in females and pectinate or bipectinate antennae in males.

Family Pergidae

These are leaf-feeding sawflies and the adults possess six-segmented antennae.

Family Tenthredinidae (typical sawflies)

This is a very large group of wasp-like, medium-sized to small brightly coloured insects. Many colour variations occur in both sexes. Many are found on flowers or foliage and some are carnivorous feeding on small insects. Parthenogenesis occurs in the family. From unfertilised eggs either males or females, and in a few cases both sexes may develop. The ovipositor is well developed and toothed in various ways.

The larvae are phytophagous feeding externally on foliage and in a few cases they may be found in stems, fruits or galls. Certain species are leaf miners. The larvae possess three pairs of thoracic legs and six to eight pairs of abdominal legs devoid of crochets. The larva pupates in an elongate-oval silken cocoon or earthen cell.

A few species of sawflies are important as pests of crops, shrubs and trees. The larch sawfly *Pristiphora erichsonii*, the imported currant worm *Nematus ribesii*, *Enura* sp. forming galls on willow and the birch leaf miner *Fenusa pusilla* are some pests of importance in the USA. In India, the mustard sawfly *Athalia lugens* is an important pest.

THE MUSTARD SAWFLY *Athalia lugens*

This is one of the very few hymenopterous insects found as crop pests in India.

The larvae eat away edges of leaves of mustard, radish, etc. and severe attack causes serious damage. The insect is prevalent during December and January and May-June.

Life history: The adult is a shining black fly-like insect with bright yellow thorax and femora. The female with its saw-like ovipositor inserts the eggs singly very near the leaf margin. A female lays from 2 to 131 eggs, the average being 61. The oval, cream coloured eggs appear over the leaf surface as yellowish-green tubercles arranged in rows. The incubation period is four to five days. There are five larval instars and in 13 to 18 days the larva becomes full-grown. The larva measures 15 to 20 mm long and is cylindrical, dark grey in colour with three pairs of thoracic legs, seven pairs of abdominal legs on segments second to eighth, and ten pairs of spiracles (two thoracic and eight abdominal). The full-grown larva enters the soil and forms an oval silken cocoon to which are attached sand and bits of vegetation. After a quiescent period of four days it changes into prepupa and finally the pupa. The cocoon may be seen up to a depth of 9 cm. The prepupal and pupal periods last for about two and four days, respectively. The entire quiescent period ranges from 10 to 15 days, the average being 13 days. Parthenogenetic development occurs in this species, the unfertilised eggs giving rise to males.

The insect attacks mustard (*Brassica campestris*), radish (*Raphanus sativas*), turnip and occasionally cabbage and cauliflower. Its infestation on radish is much more pronounced.

Control: Spraying methyl parathion 0.025 % may be useful in controlling the pest.

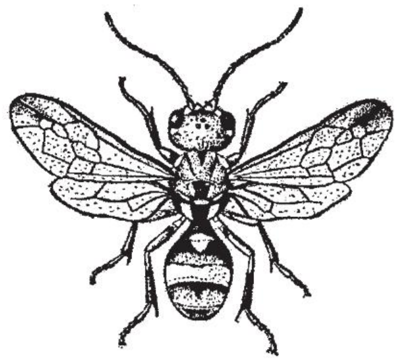
SUBORDER APOCRITA (CLISTOGASTRA)

These insects are characterised by a deep constriction between the propodeum (first abdominal segment) and the second abdominal segment. The larvae are apodous. The Apocrita have highly specialised habits and are often social. The adults generally feed on sap, flowers and other plant materials and occasionally the parasitic insects may feed on the body fluid of the host. They possess a well-developed ovipositor. In the parasitic forms such as all Ichneumonoidea, almost all the Chalcidoidea and a few Cynipoidea, the ovipositor is adapted for piercing and depositing the eggs on or in the body of the hosts. The long ovipositor in many enables them to oviposit on the host in cocoons, burrows or other protected situations. The eggs laid on a host may be single or several to many. In a few species, the phenomenon of polyembryony occurs. A few are known to be hyperparasites.

The Sphecoidea and Vespoidea are predaceous. The females of these two superfamilies and those of Apoidea may sting. Plant infesting species are met with among many of the Cynipoidea and a few of the Chalcidoidea. The Apoidea feed on nectar and pollen.

Superfamily TRIGONALOIDEA

This includes a single family Trigonalidae. These insects are characterised by a trochantellus on hindfemur, multi-articulate antennae with more than 20 segments, absence of axillary or anal lobe on hindwing, non-petiolate abdomen and vestigial ovipositor. Some of the Indian forms are: *Ischnogonalos dubia, Lycogaster rufiventris, Poecilogonalos pulchella, P. kerala* (Fig. 67.2) and *Pseudogonalos harmandi.*

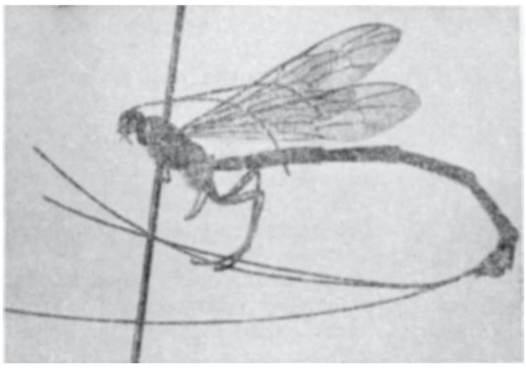


▲ **Fig. 67.2** *Poecilogonalos kerala (T. V. Ramakrishna Ayyar)*

Superfamily ICHNEUMONOIDEA

This is a very large group and members of this superfamily are all parasitic on other insects and occasionally on other Arthropoda. Economically these insects are important as they exercise check over the multiplication of injurious species and also in view of the possibilities of exploiting them for biological control of crop pests.

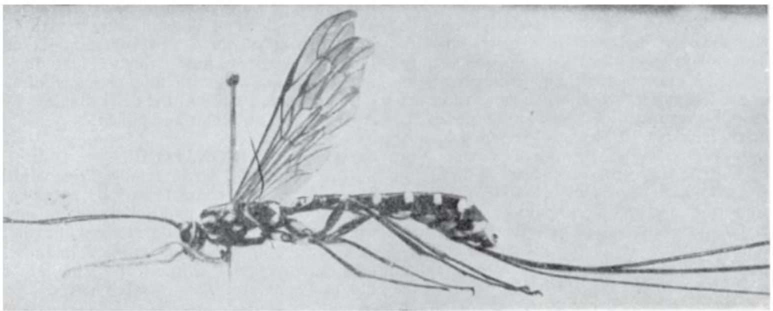
The characteristic features of ichneumonoidea are long antennae, presence of trochantellus on hindfemur, absence of anal lobe on hindwing, a distinct pterostigma and mostly narrow costal cell on forewing and the gaster attached at the bottom or a little above of propodeum.



▲ **Fig. 67.3** *Leptopimpla longiventris (Courtesy: V.K. Gupta)*

Family Ichneumonidae

The ichneumons are large, slender, black yellow or reddish yellow insects with a longer antenna having 16 or more segments (Figs 67.3 and 67.4). These are parasitic on many groups of insects and spiders and a few are hyperparasites. The adults are active on warm sunny days and frequent the flowers especially of Umbelliferae. In the subfamily Cryptinae apterous or brachypterous individuals occur. In all the others the forewing has the cross-vein 2m-Cu. The trochanters are two-segmented. The propodeum is prolonged beyond the insertion of the hindcoxa and the gaster is generally three times as long as head and thorax. The ovipositor arises anterior to the tip of the abdomen and remains extruded permanently.



▲ **Fig. 67.4** *Rhyssa persuasoria himalayensis (Courtesy: V.K. Gupta)*

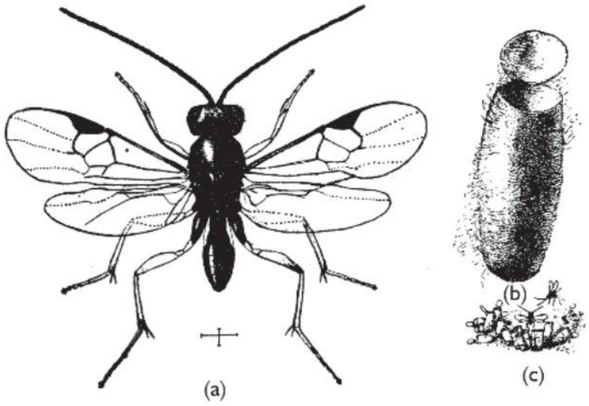
The larva in endoparasitic forms possesses a prominent caudal prolongation or tail in the earlier stages of its development, and in ectophagous forms the caudal prolongation is wanting. It pupates in a silken cocoon.

A large number of ichneumonids are known as parasites of a number of crop pests in India. A few are known to be hyperparasites. The ichneumonids *Amauromorpha accepta schoenobii, Goryphus mesoxanthus maculipennis, Ischnojoppa luteator* and *Gambroides javensis* are parasitic on the rice yellow borer *Scirpophaga incertulas. Gambroides javensis* parasitises the top borer *Scirpophaga excerptalis* of sugarcane. *Trathala flavoonbitalis, Xanthopimpla punctata* and *X. stemmator* on *Chilo partellus* and *X. emaculata* on *Cnaphalocrocis medinalis, Pelopidas mathias* and *Telicota augias*, are parasitic. *Bathyplectes anurus* and *B. curculionis* are parasitic on larvae of *Hypera postica* and on these primary parasites two other ichneumonids, *Mesochorus nigriceps* and *Pezomachus stevenii* have been observed as hyperparasites.

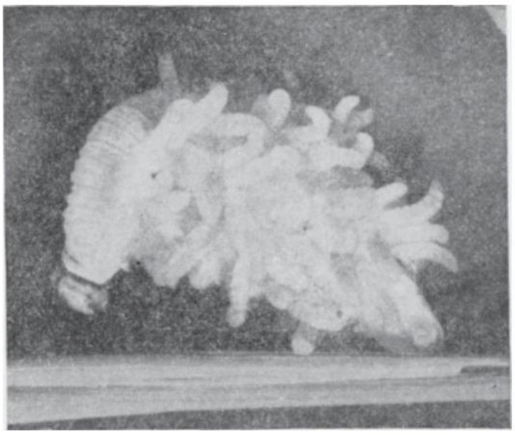
Family Braconidae

These are very small stout-bodied insects found among flowers and at light (Figs 67.5, 67.6, 67.7, and 67.8). They are distinguished from the Ichneumonidae in the crossvein 2m-Cu being absent in the forewing and therefore, there is only a single recurrent vein as against two recurrent veins in the ichneurnonids. Further, the first sector of

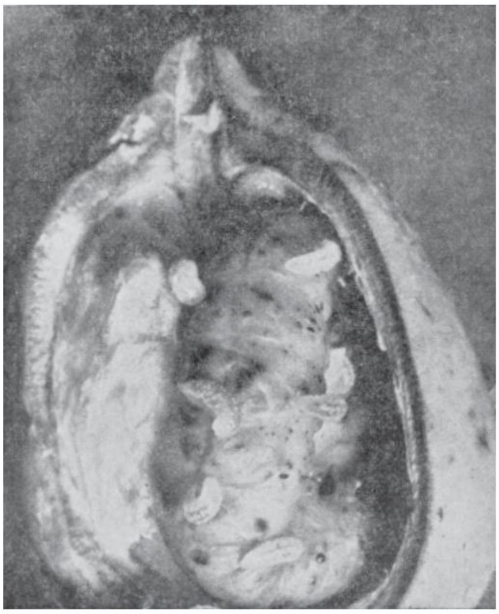
M+Rs, which is present in the Braconidae is absent in the Ichneumonidae. Sexual dimorphism is noticeable in *Sycosoter lavagnei*, an ectoparasite of the scolytid, *Hypoborus ficus* in which winged and wingless forms occur in both sexes. The abdomen of braconids is sessile, subsessile or petiolats. They are parasitic more commonly on lepidopterous insects and from a single caterpillar many individuals may arise. The larvae are similar to those found in Ichneumonidae. They pupate externally as in *Apanteles* spp. and *Cotesia* spp. in white, yellow or buff-coloured silken cocoons, or within the host as in *Rhogas* and *Aphidius*. The members of the subfamily Aphidinae (Figs 67.9 and 67.10) are known to be parasites of aphids and a single parasite issues out from each parasitised aphid.



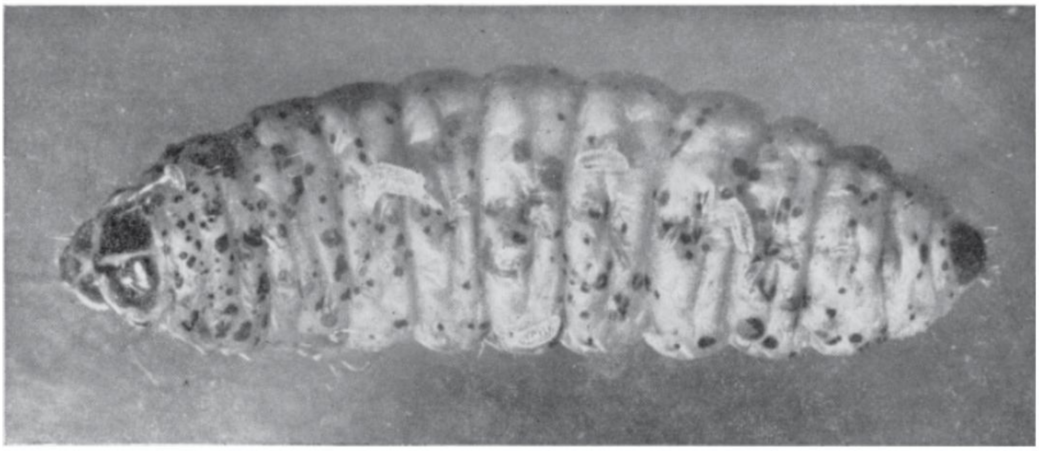
▲ **Fig. 67.5** *Cotesia glomerata, A. adult, B. cocoon, C. adult emerging from cocoon(Courtesy: US DA, Washington)*



▲ **Fig. 67.6** *Larvae of Apanteles sp. emerging from the caterpillar of Pelopidas mathias mathias (Courtesy: V.P. Rao)*



▲ **Fig. 67.7** *Young larvae of Bracon kirckpatricki feeding on pink bollworm (ibid)*



▲ **Fig. 67.8** *Larvae of Bracon kirckpatricki feeding on pink bollworm (ibid)*

Some of the common braconid parasites occurring in India are *Cotesia flavipes, Glyptapanteles colemani, Apanteles papilionis, Microplitis maculipennis, M. ophisuae, Chelonus narayani, lphiaulax spilocephalus, Rhaconotus roslinensis, Stenobracon deesae, S. nicevillei, Eugathis cryptophlebiae, Heterogamus* sp., *Aphidius* sp., *Phanerotoma* sp., *Chelonus* sp., *Opius* sp., *Bracon greeni*, *B. brevicornis*, *Microctonus aethiops, Perilitus rutilus, Dinocampus coccinellae, Spathius vulnificus, S. critolaus,* etc.

▲ **Fig. 67.9** *Aphidius sp. attempting oviposition in an aphid (ibid)*

▲ **Fig. 67.10** *Mummies of Myzus persicae caused by Aphidius sp. (ibid)*

Cotesia flavipes is a very common braconid which parasitises larvae of *Chilo partellus, C. auricilius, C. infuscatellus, C. polychrysus, C. tumidicostalis, Amsacta albistriga, Spilarctia obliqua, Chilo sacchariphagus indicus, Scirpophaga excerptalis, Sesamia inferens, S. uniformis* and *Scirpophaga incertulas* in India. The parasitoid exhibits polygamy and polyandry mating behaviour. On an average a female mates with six to seven females and a female with 11-12 males. The female oviposits up to five times and each successful pricking lasts for one to two seconds. The egg-larval, prepupal and pupal periods vary from 11-13, three to nine hours, and four to six days, respectively. The adult female and male live for five to six and three to four days, respectively. Successful adult emergence accounts for 78-96 %. Male female ration is 1:1.8. The total life cycle takes about 17 days.

Bracon brevicornis is mass multiplied and released for the control of *Opisina arenosella* on coconut in South India.

Family Stephanidae

A small group of insects measuring 5 to 19 mm in length. They are parasitic on larvae of wood-boring coleopterous insects and hence possess a long ovipositor. The antennae are long and have 30 or more segments. The hindfemur are with spines beneath.

Family Megalyridae

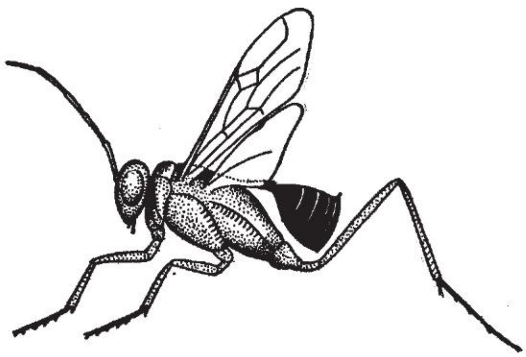
These are known from Australia and *Megalyra* sp. is parasitic on wood-boring beetles.

Superfamily EVANIOIDEA

These insects are characterised by a wider costal cell and forewing and the gaster being attached by a slender petiole to the top of propodeum above the base of the hindcoxae. This includes the following three families.

Family Evaniidae (ensign wasps)

The Evaniidae have the antennae inserted well above the clypeus, 1 or no m-cu cross-vein on forewing, an anal lobe on hindwing, short propleuron, long and abrupt petiole, compressed and short gaster and short unexserted ovipositor. On forewing 2r-m cross-vein is absent. These are black insects and carry the gaster almost like a flag and hence the common name "Ensign wasps." They are parasitic in the oothecae of cockroaches. Some common species found in India are: *Evania appendigaster* (Fig. 67.11), *E. antennalis, E. albitarsis* and *E. curvicarinata.*



▲ **Fig. 67.11** *Evania appendigaster*

Family Gasteruptiidae

These are characterised by having the propleuron forming a long "neck," swollen hindtibiae, a long gaster and often a long exserted ovipositor. An anal lobe is wanting in the hindwing. They are mainly parasitic on solitary bees and also on sphecoids and other wasps. Some Indian species are *Gasteruption orientale* and *G. mandibulare.*

Family Aulacidae

These have the antennae inserted just above the clypeus. On forewing cross-veins 2m-cu and 2r-m are present. Anal lobe is absent in hindwing. These insects are chiefly parasites of coleopterous insects. Indian species include *Aulacus bituberculatus.*

Superfamily CYNIPOIDEA

Cynipoidea are small or often minute insects, mostly black or dark coloured and sometimes apterous; in winged forms the venation is greatly reduced. The antennae are filiform and not elbowed. The pronotum extends back to the tegulae and usually trochantellus is not developed. Pygostyles are wanting. The ovipositor arises from anterior to apex of the abdomen. The eggs have a usually elongate pedicel. The larvae are apodous and maggot-like. A cocoon is absent. Its members are either gall makers, gall inquilines or parasites. This superfamily comprises of the following four families.

Family Cynipidae (gall wasps)

This is a very interesting family, which includes three subfamilies, viz. Eucoilinae and Charipinae comprising parasitic forms, and Cynipinae comprising gall makers and gall inquilines.

The Eucoilinae have a rounded elevation on scutellum and are parasitic on puparia of flies. *Eucoila eucera* is a parasite of *Oscinella frit*, *Cothonaspis* sp. are parasitic on puparia of *Bactrocera* sp. in India. *Dieucoila indica* is parasitic on puparia of the syrphid *Sphaerophoria scutellaris.*

The Charipinae are hyperparasites of *Aphidius* parasitic on aphids.

The Cynipinae or gall wasps are small to minute black insects. The forewings have not more than five closed cells and the pterostigma is absent; the hindwings possess two or three nervures. Usually these insects are winged and sometimes wings may be wanting or vestigial. The shining abdomen is oval and somewhat compressed, and the second tergite covers about half or more of gaster. In many, males are unknown. It develops parthenogenetically or sexually.

The insects are known to produce galls on all parts of plants from the roots to the flowers, or live inside galls made by other insects. Many of them are known to infest oak and others mostly infest rose and plants of Compositae. The galls produced on a articular part of a plant is very characteristic and this varies with each of the species involved. Tannic acid and certain dyes have been obtained from such galls.

In many species two generations are noticed in one year. The summer generation develops in one type of gall and emerges in the fall. These reproduce parthenogenetically as males are absent. They develop in a different type of gall and in the following summer give rise to male and female individuals. Heterogony is a remarkable feature in Cynipinae. The insects as well as the galls of the two generations are frequently quite different in appearance or form, often they may be mistaken for two different species.

The important Indian species are *Biorrhiza pallida, Callirhytis semicarpifoliae, Neuroterus quercusbaccarum lenticularis* and *Onychia striolata.* Species of *Andricus, Cynips* and *Rhodites* are also known to be gall makers on plants.

Family Figitidae

These insects are parasites of Diptera and Neuroptera.

Family Ibaliidae

These are relatively large insects, which are parasites of Siricidae.

Family Liopteridae

These are large insects and their habits are unknown.

Superfamily CHALCIDOIDEA

This is a very large group comprising some of the smallest members of Insecta. They are generally found on flowers and foliage. They are very important as parasites and hyper parasites of other insects. Phytophagous species occur in the families Agaonidae, Torymidae, Perilampidae and Eurytomidae, which infest seeds, and certain species of the latter two families are gall-makers.

The chalcids are generally 2 or 3 mm in length. The members of Mymaridae are less than 0.5 mm in length and some of Leucospididae measure 10 to 15 mm long. They are mostly dark-coloured, and others are metallic blue or green. The antennae are elbowed and never exceed 13 segments. The pronotum does not extend back to the tegula and is collar-like. A prepectus is usually seen in the side of the thorax. They possess mostly clear wings and in some the wings are either reduced or wanting.

The chalcids are parasitic chiefly on the eggs and larvae and rarely on the pupae of insects, mostly of Lepidoptera, Diptera, Coleoptera and Homoptera. Hypermetamorphosis occurs in this group. The larvae do not pupate in any cocoons.

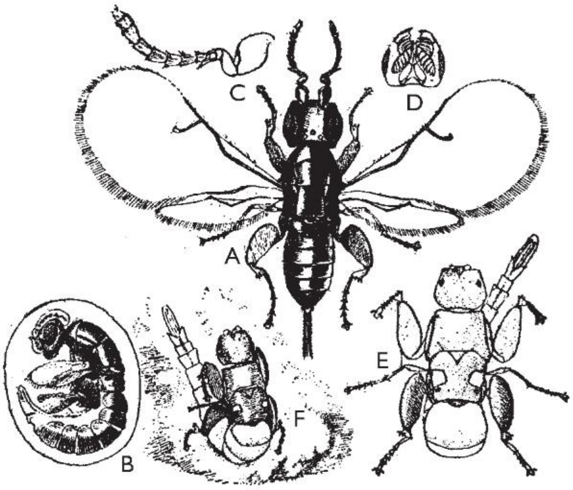
The following families are recognised.

Family Agaonidae [Agaontidae] (fig insects)

This is a very interesting family in which the males are apterous with three to nine-segmented antennae and greatly modified without showing any close resemblance to the female. The female has a long oblong head with a deep longitudinal groove above and very stout fore- and hindlegs, the middle legs being slender. The insects live within the receptacles of *Ficus* sp. and pollinate or fructify the flowers.

In California, the smyrna fig is extensively grown and as it contains only female flowers in its receptacles it requires to be pollinated with pollen from the wild fig or caprifig, as otherwise the fruits may fall without maturing. Pollination is achieved by fig insects, which develop in the caprifigs. There are two kinds of female flowers, long-styled and short-styled, and the fig insects oviposit in the ovaries of short-styled (also termed as gall-flowers) female flowers which give rise to galls; inside galls the development is completed. The males emerge first and fertilise the females while they are inside the galls. The females that emerge get covered up with the pollen of the caprifig. They come out of the receptacle and visit other flowers and once they enter the receptacles commence oviposition. They oviposit only in the flowers of caprifig. However, smyrna fig growers place the caprifigs in the smyrna trees so that the females that come out of the caprifigs laden with pollen are certain to visit the flowers of smyrna fig. Within the receptacle of Smyrna fig they are unable to lay eggs due to the different shape of flowers and after moving about inside they usually leave the receptacles, however, this process brings about pollination. The males mostly die within the receptacles of caprifig. Interesting investigations have been carried out on the symbiotic relationships between figs and fig insects.

In the United States two species of fig insects occur, viz. *Blastophagus psenes* (Fig. 67.12) in California and Arizona and *Secundeisenia mexicana* in Florida, the former being an introduced species. *Blastophagus psenes* is associated with *Ficus carica.* In the Phillippines *B. notata*



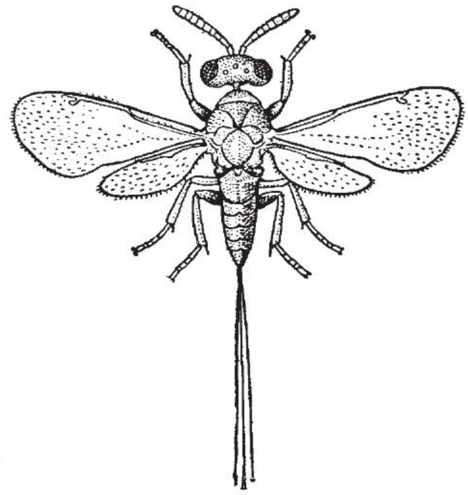
▲ **Fig. 67.12** *Blastophagus psenes—A. adult female with wings spread, B. female still in gall, C. antenna of female, D. head of female from below, E & F adult males (Courtesy: USDA, Washington).*

is the inhabitant of the receptacles of *F. notata*. In India *B. breviventris* is found in edible figs. The other Indian species of Agaonidae associated with *Ficus* sp. are: *Euprestina masoni* females with grooved (sulcate) head; *Blastophaga breviventris*, *Sycoscapta insignis*, and *Sycophila saundersi* being insects found in edible figs.

Family Torymidae

These are somewhat elongate insects with large hindcoxae, simple or single toothed hindfemur and an exserted long ovipositor. The parapsidal sutures are distinct. Both parasitic and phytophagous species occur in this family. Species of Toryminae, Erimerinae and Monodontomerinae are parasitic on caterpillars and gall insects. *Monodontomerus trichiophthalmus* is parasitic on larvae of leaf-cutting bee in India. In South India, the grubs of the seed infesting chalcid *Bruchophagus mellipes* are parasitised by *Eridontomerioidella gibboni* (Fig. 67.13).

The species of Megastigminae and Idarninae attack seeds and figs. Some of the Indian species of Idarninae, *Idarnes testacea, Apocrypta westwoodi* and *Eokoebelia brevitarsus*, etc. attack *Ficus glomerata*.



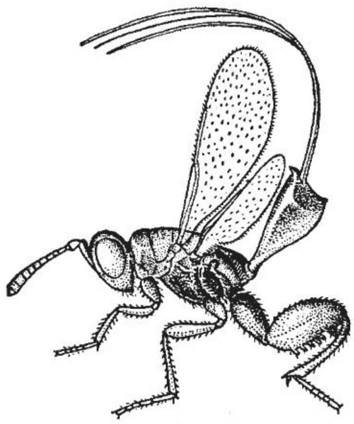
▲ **Fig. 67.13** *Eridontomerioidella gibboni, female (M.S. Mani, General Entomology, 1968)*

Family Ormyridae

These differ from Torymidae in having indistinct parapsidal sutures and a short ovipositor. These are parasites of gall insects.

Family Podagrionidae

The Podagrionidae possess four to eight long teeth on hindfemur and a long straight ovipositor. They are parasites of mantid eggs. Some of the Indian species are *Pachytomus mantisiphagus, Podagrion mantoidae* (Fig. 67.14) and *P. pachymerum.*

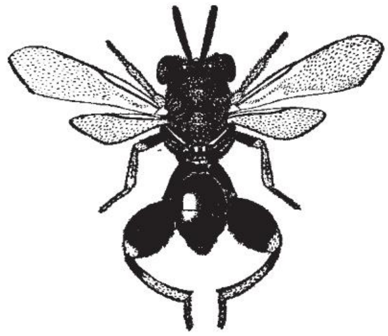


▲ **Fig. 67.14** *Podagrion mantoidae female (ibid)*

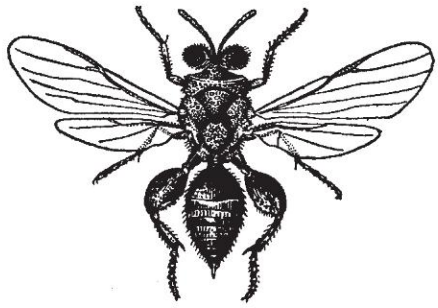
Family Chalcididae

Chalcididae are characterised in possessing rows of short teeth on hindfemur, which is greatly swollen. When at rest the wings are not folded longitudinally. Prepectus is wanting. The ovipositor is straight and short. These insects are parasites of Coleoptera, Diptera, Lepidoptera and Neuroptera. Some are hyperparasites on other hymenopterous and dipterous insects.

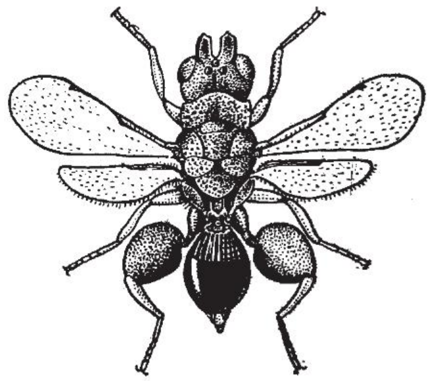
The Indian species are: *Meyeriella indica, Oncochalcis nursei, Brachymeria argentifrons, B. hearseyi* var. *xanthoterus* (Fig. 67.15), *B. excarinata, B. plutellophaga, Spilochalcis fletcheri, Euchalcis myrmeleonae, Antrocephalus destructor, A. renalis, Stomatoceras ayyari* (Fig. 67.16), *Dirhinus pachycerus,* (Fig. 67.17), *etc. Brachymeria nephantidis* is parasitic on larvae of *Opisina arenosella.*



▲ **Fig. 67.15** *Brachymeria hearseyi var. xanthoterus (Courtesy: K.J. Joseph)*



▲ **Fig. 67.16** *Stomatoceras ayyari (Mani, 1968)*



▲ **Fig. 67.17** *Dirhinus pachycerus female (ibid)*

Family Leucospididae

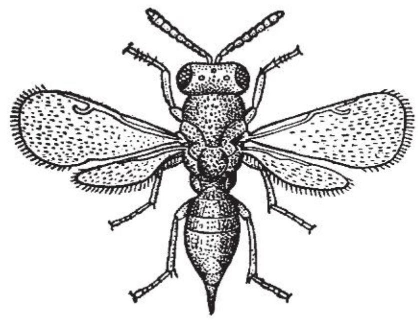
These are black and yellow, stout bodied insects with the wings folded longitudinally when at rest. Prepectus is distinct. The hindfemur is swollen with rows of short teeth. The ovipositor is long and bent forward over abdomen. These are parasitic on wasps and bees. In India *Epexochlaenoides pyriformis* is parasitic on the eurnenid wasp *Rhynchium nitidulum.* The other Indian species are *Polistomorpha indica* and *Leucospis* sp.

Family Eurytomidae (seed chalcids)

These are black or yellowish slender insects with coarsely punctate thorax, and more or less compressed rounded or ovate gaster. Both phytophagous and parasitic forms occur.

Harmolita attack stems of wheat, rye, barley and various grasses and produce galls on them. *H. orchidearum* produces galls on stems and leaves of certain orchids. Species of *Eurytoma* infest seeds of fruit trees and *E. samsonovi* is a well-known pest of apricot.

Bruchophagus mellipes infests the seeds of the legumes *Sesbania grandiflora* and *S. aculeata* in South India. Some species of *Eurytoma* are primary parasites of certain insects. *Eurytoma curculionum* on *Hypolixus truncatulus* (amaranthus weevil), *E. monemae* on *Latoia lepida, E. pigra on Alcidodes bubo, E. nesiotes* on gingelly gall midge *Asphondylia sesami,* and *E. setitibia* (Fig. 67.18) on nymphs of psyllid *Trioza fletcheri* are some parasitic forms in India. *Prodecatoma pongamyiae* is parasitic on *Asphondylia pongamyiae.* The following are some hyperparasites: *Eurytoma albotibialis* on *Goniozus nephantidis*, *E. pallidiscapus* on *Holcocera pulverea, Axiomopsis* sp. on *Bracon chinensis* and *Microplitis maculipennis*, etc.



▲ **Fig. 67.18** *Eurytoma setitibia, female*

Sycophila sp. has been noticed to be a pest of *Jasminum grandiflorum* and the larva bores into the tender shoot and feeds on the inner content hollowing out the stem. The affected twigs dry up. The adult wasp lays whitish eggs inside the bark of tender shoot. The larva pupates inside the hollowed out shoot. The incidence on the crop is noticed from June to October. It is parasitised by an eulophid *Chrysonotomyia ?cinctiventris* (Ashmead).

Family Perilampidae

The Perilampidae are metallic green or black stout-bodied insects with coarsely punctate large thorax and small, triangular abdomen. They are mostly hyperparasites and a few are primary parasites. The insects lay eggs on foliage and the planidium type of larvae get themselves attached to the larval host found on the foliage and enter its body. The perilampid larvae remain inside the larval host till the primary parasite of the host larva pupates, and then attack it. They attack the pupae of tachinids, ichneumonids and braconids parasitic on caterpillars. If the host larva is not parasitised by any one of the parasitic insects the perilampid larvae may not develop further.

Perilampus microgastris is parasitic on the primary parasites, *Microgaster indicus* and *Apanteles machaeralis* of *Eutectona machaeralis*, and *Apanteles taragamae* on *Opisina arenosella* in India.

Family Eucharitidae

The insects are black or metallic blue or green with somewhat hump-backed thorax having spines on the scutellum and petiolate abdomen. These are tropical insects and are ectoparasites of pupae of ants.

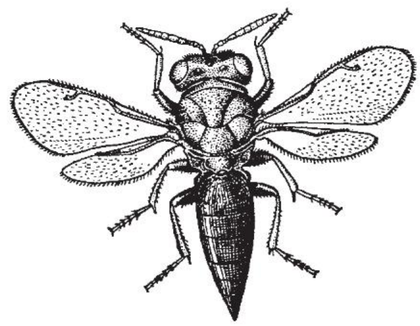
Family Pteromalidae

Pteromalidae are found in large numbers parasitising a wide variety of insects of economic importance. They are minute, black or metallic green or bronze in colour with large but short thorax and small subtriangular gaster. The second or fused second and third tergites cover most of the surface of the gaster. In many species the adult female feeds on the body fluid that exudes through the puncture made on the body of the host by its ovipositor. It is interesting that the female of *Habrocytus cerealellae* penetrates its ovipositor into the seed containing the larva of *Sitotroga cerealella* and secretes a viscous liquid, which forms a tube extending down to the larva and through which it sucks the body fluids.

Some of the important Indian species are as follows: *Cardiogaster secundus* is parasitic on the aleyrodid *Aleurolobus barodensis.* The eggs of the pentatomid, *Urostylis punctigera,* is parasitised by *Pachyneuron pentatomivora.* The puparia of *Leucopis nigricornis* is parasitised by *Pachyneuron leucopiscida. Scutellista cyanea* is a parasite of a wide variety of scale insects. The grubs of the buprestid stem borer *Sphenoptera gossypii* are parasitised by *Neocatolaccus indicus* and *N. sphenopterae.* The pteromalids *Catolaccus aeneoviridis*, *Dibrachys boucheanus* and *Habrocytus crassinervis* are hyper-parasites of the primary larval parasite *Bathyplectes anurus* (Ichneumonidae) of *Hypera postica.*

Family Miscogasteridae

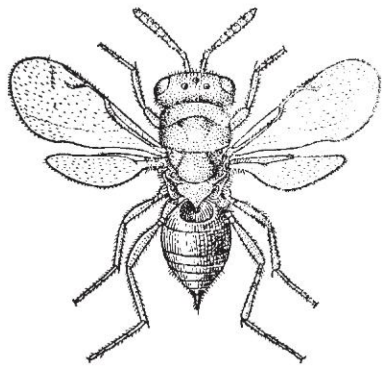
These are parasites of dipterous insects. *Ecrizotomorpha taskhiri* is either a hyper-parasite or secondary parasite of the linseed gall midge *Dasineura lini. Systasis dasineurae* is also parasitic on *D. lini. Hypolixus truncatulus* is parasitised by *Dinarmus sauteri* (Fig. 67.19). *Bruchobius colemani* and *B. laticeps* (Fig. 67.20) are parasites of *Bruchus* sp., *Anysis alcocki* and *A. saissetiae* are parasites of scale insects. The grub of *Caryedon gonagra* is parasitised by *Oedaule stringifrons.*



▲ **Fig. 67.19** *Dinarmus sauteri female*

Family Encyrtidae

Encyrtidae are small insects measuring 1 to 2 mm long and are widely distributed. The mesopleura are broad and convex and do not possess a groove for the femora. Long bristles are wanting in midtibia. Polyembryony occurs in a number of species. These insects are parasites of aphids, whiteflies, scales, etc.



▲ **Fig. 67.20** *Bruchobius laticeps female*

In India *Anabrolepis bifasciata, Anagyrus saccharicola, Anicetus ceylonensis, Aphycus flavus, A. fusidorsum, Comperiella bifasciata, C. indica, Encyrtus barbatus, Eucomys lecaniorum, Krishnieriella ceroplastodis, Leptomastidea indica, Paraleptomastix dactylopii, Prochiloneurus nippaecocci, Tetracnemus indicus*, and *Tyndarichus hemiaspidoproctis* are some parasites of coccids. *Paracopidosomopsis javae* is parasitic on *Argyrogramma signata*. The grubs and pupae of certain coccinellid beetles are parasitised by *Homalotylus flaminius*. *Cheiloneurus pyrillae, Ooencyrtus pyrillae* and *Ageniaspis pyrillae* are parasitic in the eggs of *Pyrilla perpusilla*.

Family Eupelmidae

These insects are characterised by flat mesonotum and presence of parapsidal furrows. Many are capable of jumping. Apterous or short-winged forms occur in some. These are parasitic on insects and spiders. In India, *Eupelmus carinatus* and *E. tenuicornis* are parasitic on gall midges. Grubs and pupae of *Bruchus* sp. are parasitised by *Bruchocida orientalis*. The other parasitic insects are *Anastatus blattidarum* on oothecae of cockroach, *A. coimbatorensis* on eggs of *Oxya nitidula, A. colemani* on eggs of the pentatomids, *Degonetus serratus*, and *Tetroda histeroides*, and *Eupelmus urozonus* and *Eupelmella pedatoria* on the cotton stem weevil *Pempherulus affinis*.

Family Thysanidae

Members of this family are parasites of coccids, aleyrodids, other homopterous insects and rarely Diptera. Some are hyperparasites of chalcids.

Family Tanaostigmatidae

These are parasites of coleopterous insects, especially weevils. However, a few are pod wasps.

THE PIGEON PEA POD WASP *Tanaostigmodes cajaninae*

This pod wasp was first reported from Hyderabad during 1977. It has now been reported to be a potential pod borer causing considerable damage in Tamil Nadu and Andhra Pradesh. The damage is more pronounced in short life cycle types than in medium and long life cycle types, and ranges from 3–50 %. It also infests wild relatives of pigeon pea *Atylosia* sp. and *Rhynchosia* sp.

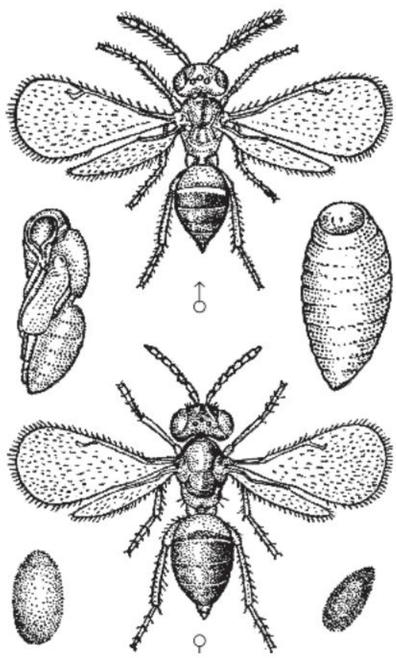
The adult wasp is small with bluish-black head and thorax. It shows peculiar preference for the locule adjacent to the fruit stalk. There will be a characteristic minute pin-hole on the locule adjoining fruit stalk through which the adult emerges. The larva is straw coloured and pyriform in shape. It gnaws at the seeds and pupates inside the damaged locule. Need based spray application of monocrotphos 0.04% or chlorpyrifos 0.05% or endosulfan 0.07% or neem oil 3% or neem seed kernel extract 5% has been suggested.

Family Eulophidae

Eulophidae are small insects measuring about 1 to 3 mm long and are parasitic on the eggs, larvae and pupae of a wide variety of insects, especially of Homoptera, Coleoptera, Lepidoptera and Diptera. They possess four or five segmented tarsi and the axillae extend in front of anterior margin of scutellum and usually beyond the tegulae. The antennae are pectinate in males of many species.

Eulophidae are mostly parasitic and a few are hyperparasites. It is interesting that in the genus *Coccophagus* the female larva is an internal parasite of the scale insect whereas the male larva may be a hyperparasite of other parasites attacking the scale insect or may attack the female larva of its own species. In *Euplectrus* a cocoon is found and in all other cases it is wanting.

Trichospilus pupivora is a well known parasite in India which is mass multiplied and utilised for the control of the coconut black-headed caterpillar *Opisina arenosella. Euplectrus euplexiae, E. leucostomus, Tetrastichus ayyari, T. ophisuae, T. schoenobii* are parasitic on lepidopterous insects. A number of lepidopterous leaf miners and leaf rollers are also parasitised by eulophids. *Euryscotolinx coimbatorensis* on *Cyphosticha caerulea*, *Euplectrus busyi* on pongamia leaf miner, *Cirrospilus phyllocnistoides* and *Scotolinx quadristriata* on *Phyllocnistis citrella*, and *Asympiesiella indica* on *Gracillaria soyella* are some examples. The role of *Aphelinus mali* in the biological control of the woolly aphis *Eriosoma lanigera* is well known. *Aphelinus fuscipennis, Praspaltella lahorensis* and *Azotus delhiensis* are very common parasites of aleyrodids. *Tetrastichus pyrillae* (Fig. 67.21) is an egg parasite of *Pyrilla perpusilla. T. radiatus* parasitises the psyllid *Diaphorina citri. Aphelinus mytilaspidis*, *Coccophagus tschirchi*, *Marietta javensis* and *M. leopardina* are some parasites of coccids. Eulophids parasitic on coleopterous insects include *Cassidocida aspidomorphae, Euderus gossypii, E. pempheriphila, Pleurotropis epilachnae, Tetrastichus colemani, Euderus lividus, Melittobia indica, Tetrastichus coimbatorensis* and *Hyperteles longicauda* are parasites of dipterous insects. *Tumidiscapus oophagus* is parasitic in eggs of *Oxya nitidula*. The nymphs of the thrips *Rhipiphorothrips cruentatus* are parasitised by *Thriptoctenus maculatus*.

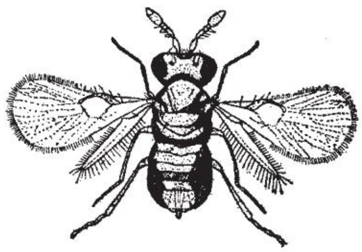


▲ **Fig. 67.21** *Tetrastichus pyrillae (M.S. Mani, 1968)*

Family Trichogrammatidae

These are very minute insects measuring 0.3 to 1.0 mm long and are characterised by three-segmented tarsi and broad forewings with rows of microscopic hairs on them. They are parasitic on eggs of a large number of insects of Lepidoptera and *Trichogramma* spp. (Fig. 67.22) have been extensively utilised in biological control of crop pests.

In India, *Lathromeroides* sp. is an egg parasite of the leaf rolling weevil *Apoderus sissu*. *Trichogramma chilonis* is an egg parasite of the sugarcane shoot borer *Chilo infuscatellus, C. partellus,* etc. Its utility in the biological control of the sugarcane shoot borer has been promising in South India. *T. japonicum* parasitises the eggs of *Scirpophaga incertulas*. The eggs of *Nephotettix virescens* are parasitised by *Oligosita nephotettica* and *Westwoodella nephotettica*.



▲ **Fig. 67.22** *Trichogramma sp.*

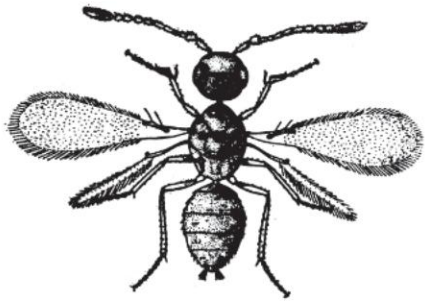
Family Elasmidae

Elasmidae are small brown or black elongate insects with enlarged, compressed hindlegs. They are primary parasites of lepidopterous insects or hyperparasites of braconids and ichneumonids parasitic on lepidopterous larvae.

Elasmus zehntneri, E. johnstoni, E. indicus, E. brevicornis, E. nephantidis, etc. are some Indian species. *E. albomaculatus* is a hyperparasite of *Apanteles malveolus.*

Family Mymaridae (fairyflies)

Mymaridae are extremely minute (less than 1.0 mm long) black or yellowish insects which are parasitic on eggs of insects (Fig. 67.23). *Alaptus magnanimus* measures 0.21 mm long. The eggs of certain aquatic Hemiptera are parasitised by some myrnarids. Both sexes of *Polynema natans* swim beneath the water using their wings and parasitise *Notonecta. Anaphes* sp. and *Potasson (Anaphoidea) conotracheli* are egg parasites of the weevil *Hypera postica*. *Arescon enocki*, *Anagrus empoascae*, and *Lymaenon empoascae* are the mymarid egg parasite of *Empoasca devastans* in India.



▲ **Fig. 67.23** *A mymarid, (Subba Rao)*

Superfamily PROCTOTRUPOIDEA (SERPHOIDEA)

Proctotrupoidea are small, black insects, which are parasitic on eggs, larvae and pupae of other insects. A few are hyperparasites and certain forms are inquilines. The insects are frequently apterous and in winged forms the venation is much reduced. The pronotum extends laterally to the tegulae. The ovipositor generally arises from the abdominal end. The larvae pupate mostly in cocoons and in aphid-infesting species the pupa is seen within the body of the host.

This superfamily includes the following families: Platygasteridae, Scelionidae, Diapriidae, Vanhorniidae, Monomachidae, Pelecinidae, Roproniidae, Heloridae, Proctotrupidae and Ceraphronidae. The following are some important families.

Family Scelionidae

Scelionidae are small insects parasitic on eggs of Orthoptera, Dictyoptera, Lepidoptera, Hemiptera and occasionally of spiders. The phenomenon of phoresy, i.e. transportation by attaching itself to another, is noticed in some species, which are parasitic in the eggs of mantids and grasshoppers. The female scelionid attaches itself to the female of the host species and gets itself transported to the site of oviposition.

Telenomus beneficiens is parasitic on eggs of *Scirpophaga incerlulas*, *S. excerptalis*, etc. and *T. colemani* on eggs of the pentatomid *Dolycoris indicus. Scelio hieroglyphi* attacks the eggs of the rice grasshopper *Hieroglyphus banian. Hadronotus fulviventris* is parasitic on eggs of the coreid bug *Clavigralla gibbosa*.

Family Platygasteridae

These are minute black insects with ten-segmented antennae and in several species polyembryony is noticed. They are parasites of aleyrodids and cecidomyiid flies. In the female of the genus *Inostemma* a long handle-like structure is seen arising on the first abdominal segment and extending forward over the thorax and this acts as a receptacle for the ovipositor. Some common Indian species are:

Inostemma indica on the gall midge *Lasioptera cephalandrae; Polygnotus* sp. and *Plalygaster oryzae* on the rice gall midge *Orseolia oryzae* and *Amitus aleurolobi* on the sugarcane aleyrodid *Aleurolobus barodensis*.

Superfamily BETHYLOIDEA

Bethyloidea are parasitic on other insects. These insects are characterised by absence or poor development of a trochantellus. An anal lobe is usually present in hindwings. The ovipositor is short.

This superfamily includes the following families: Sclerogibbidae, Dryinidae, Embolemidae, Chrysididae, Bethylidae and Cleptidae. The following are some important families:

Family Dryinidae

Dryinidae are parasites of cicadellids, membracids and fulgorids. They possess ten-segmented antennae and in the female the foretarsi are pincers-like. In a few cases polyembryony occurs. In several species the females are wingless.

Pachygonatopus sp. parasitises the nymphs and adults of the rice white-backed plant hopper *Sogatella furcifera* in India. The adults are dimorphic, the female being apterous and ant-like in appearance and the male being winged and black in colour. *Anteon* sp. is a nymphal parasite of *Idioscopus* sp. on mango.

Family Bethylidae

Bethylidae are ant-like, small to medium sized, dark-coloured insects parasitic on larvae of Lepidoptera and Coleoptera. A few species are capable of inflicting stings on humans. Many species are apterous. In a few, winged and wingless forms occur in both sexes.

Goniozus nephantidis is a well-known parasite of the coconut caterpillar *Opisina arenosella* in India. It is mass multiplied and released periodically for biological control of the pest on coconut. *Goniozus indicus, Trissomalus fulvicornis*, etc. are other species occurring in India.

Family Chrysididae (cuckoo or ruby-tailed wasps)

These are small green, green and ruby or blue coloured insects with usually coarsely sculptured body. The venation on forewing is fairly complete and hindwing is without closed cells. The gaster is ventrally flat or concave and only three or four segments are visible dorsally. The ovipositor is concealed and retractable. The insect when disturbed curls up in a ball. They are ectoparasites of larvae of bees and wasps. A species of *Chrysis* is parasitic on the slug caterpillar *Spatulicraspeda castaneiceps* in South India.

Superfamily SCOLIOIDEA

The Scolioidea have the pronotum appearing more or less triangular in lateral view and the lateral angles extend back to or nearly to, the tegulae. They are usually parasites of larvae of coleopterous insects. Sexual dimorphism is noticed in this group. This includes the following families: Plumariidae, Scoliidae, Mutillidae, Sapygidae and Tiphiidae.

Family Scoliidae

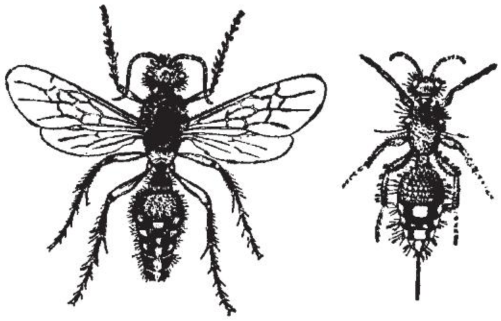
The Scoliidae are characterised by a continuous meso- and metasternum, overlying the bases of mid- and hindcoxae. In the female the wing membrane is striolate and the last sternite in the male is produced into three spines. The insects are large, hairy and black with yellow or red bands. The wings have a metallic iridescence and are often dark coloured. They are ectoparasitic on the grubs of Scarabaeidae and rarely of Curculionidae. The female burrows into the soil in search of the host, paralyses it by stinging, constructs a cell around the grub and oviposits. In biological control some of these predatory wasps have been found useful. In Hawaii the beetle *Anomala orientalis* has been successfully controlled by *Scolia manilae.* The scarabaeid beetle Oryctes is attacked by *Scolia flavifrons.* Some of the Indian species known are: *Scolia quadripustulata, S. aureipennis*, *S. bilunata* and *S. histrionica.*

Family Tiphiidae

The tiphiidae are hairy, black, fair-sized wasps with short legs and are parasites of scarabaeid and cicindelid beetles, bees and wasps. They possess non-striolate wing membrane and the meso- and metasternum do not form a plate. Rarely three spines are present on the last sternite of male. In some the females are apterous and ant-like. In such cases during mating flight the males carry the females on their back and when the males visit the flowers the females get their food. *Tiphia rufofemorata* and *T. hirsutum* are species noticed in India.

Family Mutillidae (velvet ants)

Mutillidae are densely pubescent and usually brightly coloured with red, orange or yellow markings. The apterous ant-like females may inflict a painful sting. The males are mostly winged and in others wings may be wanting. They are parasitic on wasps and bees, and certain beetles and flies. Mutillid wasps are fairly common all over India. In *Spilomutilla* sp. both sexes are apterous. In *Darylabris argentipes* (Fig. 67.24) the male is winged and the female apterous.



▲ **Fig. 67.24** *Darylabris argentipes (T.V.R. Ayyar, 1940)*

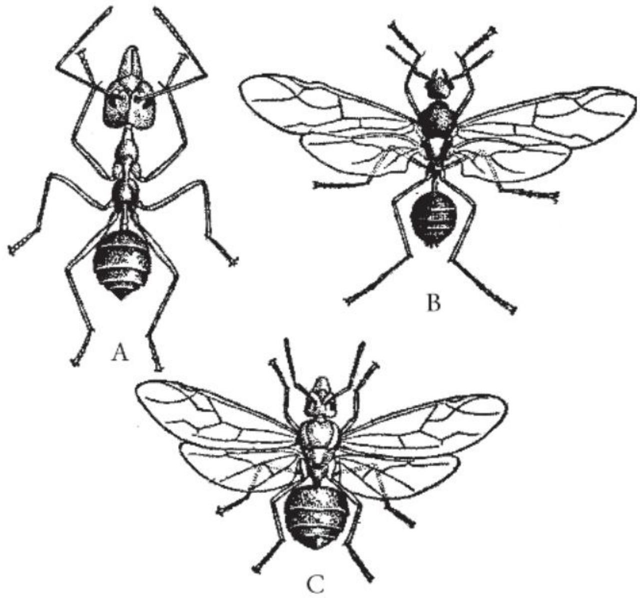
Family Sapygidae

These are small insects, which are parasitic on the nests of bees of the family Megachilidae.

Family Formicidae (Ants)

These insects are characterised by elbowed antennae with first segment being long and one-or two-segmented and nodiform or scale-like pedicel following the propodeum. In a colony three castes, viz. queens, males and workers, are recognised. The bulk of the colony consists of the sterile females or workers. The head of the ant is variable in shape with well-developed mandibles. The labrum is vestigial. The maxilla consists of all usual parts with toothless membranous laciniae and one- to six-segmented palpi. The labium consists of the submentum, prementum, median glossa, a pair of paraglossae beset with rows of setae and one- to four-segmented palpi. The antennae are 4- to 13-segmented. In the male there is an additional segment in each of the antennae than in the female or worker. Males possess well-developed compound eyes and ocelli, which are reduced or vestigial in workers and females. The queens are longer with wings, which are shed after nuptial flight. The males are smaller and die soon after mating. In a few species of *Ponera* the males are wingless. Polymorphism is well exhibited in ants, and especially in larger colonies in each of the castes two or three types of individuals varying in size shape, etc. occur. In dimorphic workers the larger type with large head and mandibles is known as the soldier ant.

The ants live in nests of various types. The nests may be found in cavities in stems, nuts, galls, excavated galleries in wood or in the ground. In the ground, the nests may be small and simple or elaborate and large with temporary brood and food chambers, fungus-gardens, etc. The red tree ant *Oecophylla smaragdina* (Fig. 67.25) fastens the leaves with silken thread and lives inside such leaf nests. In tropical and sub-tropical forest on trees certain species of ants construct suspended nests made of earth, carton or silk, which contain galleries and chambers.



▲ **Fig. 67.25** *Oecophylla smaragdina—A. soldier, B. & C. winged adults*

The ants feed variously. Some are carnivorous feeding on dead and live animals. Some are fungivorous. Some infest plants and seeds. Many are known to feed on sap, nectar, honeydew and the like. Trophallaxis or mutual feeding rituals is a common phenomenon among ants. Ants attend on other phytophagous insects for their honeydew excretion and in turn the ants render certain services to them. Such a symbiotic relationship is noticed in the association of ants with other insects such as aphids, coccids, membracids, psyllids, aleyrodids and larvae of Lycaenidae.

Certain other insects are also known to visit or inhabit regularly the nests of ants and they are called as myrmecophiles or ant-guests. The following classes of myrmecophiles are recognised.

1. The *synechthrans*: Certain staphylinid beetles live either as scavengers or predators feeding on the brood, dead or diseased ants, refuse, etc. Such species occur in the genera *Myrmedonia, Myrmoecia, Lamprinus, Quedius, Xantholinus,* etc. of Staphylinidae. They are treated with marked hostility. 2. The *synoeketes*: They live in the nests of ants without being taken cognisance of their presence by the ants. Such instances are met with in the larvae of the syrphid genus *Microdon*, Collembola of the genus *Cyphoderus*, larvae of the beetles *Clytra* sp. (Chrysomelidae) and *Dinarda* sp. (Staphylinidae), various Phoridae (Diptera), etc. These are indifferently tolerated guests. Certain Thysanura, cockroaches (*Attaphila*) and crickets (*Myrmecophila*) are also found. 3. The *symphiles* are true guests. These insects are licked, fed and even reared by ants. The symphiles are found in *Lomechusa* group of Staphylinidae, Paussidae and Clavigeridae (Coleoptera). 4. *Parasites*: chalcids (*Orasema* sp.), eucharitid genera (Hymenoptera), the phorid *Metopina* (Diptera) and the gamasid mite *Antennophorus*. Certain parasitic Hymenoptera, *Myrmecolax* sp. (Strepsiptera), several phorids and conopids and the nematode *Mermis* are endoparasites of ants.

Social symbiosis between different species of ants exists in many cases. In a compound nest two different species of different genera may live together keeping their broods separate. In some instances the smaller ants having nests close to larger species either feed on refuse of the latter or waylay its workers and get their food. Temporary social parasitism is noticed in certain cases wherein a queen settles in the nest of another species of ant and her first brood is reared by the workers of the colony. In course of time the host-queen is eliminated which is followed by the gradual death of the workers of the host species, resulting ultimately in the complete occupation of the colony by the parasitic ant. Certain species of ants in the northern hemisphere are slave-makers—they utilise certain other species as slaves. *Formica fusca* and its allies are made slaves of the ant *Formica sanguinea*.

Ants possess certain means of defense. Many species, excepting those of Dolichoderinae, are capable of stinging. Many bite often severely. A foul-smelling secretion is given off or ejected by the genera of Dolichoderinae and some species of Myrmicinae.

At certain seasons of a year queens and males are produced in large numbers in most colonies, which come out and engage in nuptial flights. The female after the nuptial flights sheds her wings, settles in a suitable place, makes a small excavation, remains in seclusion without feeding until the eggs mature and lays eggs to form the first brood. However, exceptionally the queen in a few Ponerines forages for food. The queen attends on the first brood which gives rise to workers. Thereafter, the workers look after the colony and the queen completely devotes her attention to egg laying. The queen is chiefly concerned with egg laying and establishing a new colony. In certain cases the queen may settle in the nest of an alien species. The longevity of queens in some cases is several years. Normally a colony has a single queen but in some more than one queen may be found. The workers attend to construction of the nest, caring for the young, gathering food, etc. In some species, certain castes or types of individuals may be produced after several years in a colony.

The family Formicidae comprises of the following seven subfamilies.

Subfamily Myrmicinae

This is the largest subfamily and its members are characterised by the two-segmented pedicel. The ants, which feed on seeds and store them in their nests are known as harvester ants. In India the ants *Monomorium salomonis* and *Pheidole sulcaticeps* var. *punensis* attack the seeds of sorghum sown in fields. In the USA *Solenopsis molesta* attacks sorghum seeds in the field. In India *Holcomyrmex scabriceps* feeds on wheat grains. Leafcutting ants are also met with. *Solenopsis geminata* damages seedlings of *Solanum melongena* (egg-plant) and *Cajanus cajan* (pigeon pea) by chewing holes in the leaves. In South India *Crematogaster dohrni artifex* is a very common carton-building species on the hills. The other species observed in India are *C. rothneyi, C. contempta, C. subnuda* and *C. anthercina*. In the nests of *C. dohrni artifex* a thysanuran *Lepisma subnigrina cotygii* is seen. The common household ants are *Monomorium gracillimum*, *Myrmicaria brunnea* and *Solenopsis geminata*. The red ant *Oecophylla smaragdina* is a nuisance on mango, citrus, coconut, and garden plants. In the nests of the red ant, the larvae of the lycaenid *Liphyra brassolis* are found and the ants lick them for their secretion.

Subfamily Leptaleinae (Pseudomyrminae)

The males of these ants are characterised by the two-segmented pedicel and large eyes occupying almost half the side of the head. Ocelli are usually seen. These ants inhabit hollow twigs, galls or cavities in plants.

Subfamily Dorylinae

Dorylinae are characterised by eyes being absent or vestigial. Ocelli are absent. The queens are apterous. They are predaceous. *Dorylus labiatus* attacks other ants (*Pheidole*) and also potato tubers in the field. *Dorylus orientalis* damages potato, cabbage, cauliflower, etc. in the field.

Subfamily Cerapachyinae

These ants have a distinct constriction between the first and second segments of the gaster. A conical dorsal spine or pedicel may be present. Sting is well developed. These are predaceous in habit.

Subfamily Ponerinae

The pedicel is single-segmented and a distinct constriction between the first and second segments of the gaster is evident. These ants inhabit rotten logs, stumps or may live in the soil beneath various objects. They are carnivorous in habit

Subfamily Formicinae

The pedicel is single-segmented and the anal orifice is terminal and circular. They are distributed widely. *Camponotus compressus* is the common black ant found in South India attending on aphids, coccids and aleyrodids for their honeydew. The ants *Polyergus* sp. are slave-makers. Many of *Formica* species are mound-builders. Some of the ants of the genus *Myrmecocystus*, store the honeydew collected by other workers in the mounds and such individuals are termed repletes. The ants of this group are commonly called honeyants.

Subfamily Dolichoderinae

The pedicel is single-segmented and a constriction between the first and second segments of the gaster is wanting. These ants are capable of ejecting a foul-smelling liquid from the anus.

Superfamily POMPILOIDEA

This superfamily includes two families, viz. Pompilidae and Rhopalosomatidae. Pompilidae is the most important.

Family Pompilidae

Pompilidae are called as spider wasps as they prey mostly upon spiders. These wasps are mostly dark coloured with smoky or yellowish wings. Some are brightly coloured. They measure 1 to 2.5 cm long but a few are 7.5 cm long. A characteristic suture is present across the mesopleura. The hindlegs are very long and spiny. A definite pedicel in the abdomen is wanting. The females possess a powerful sting. These insects have their nests in burrows in the ground and provision them with paralysed spiders for the young ones. In certain cases such as *Pseudagenia*, the nests are attached to stones or walls. Some of the Indian species are *Hemipepsis perplexus, Pompilus analis, P. acceptus, Pseudogenia rava, Salius consanguineus* and *S. flavipennis.*

Superfamily VESPOIDEA

Family Vespidae

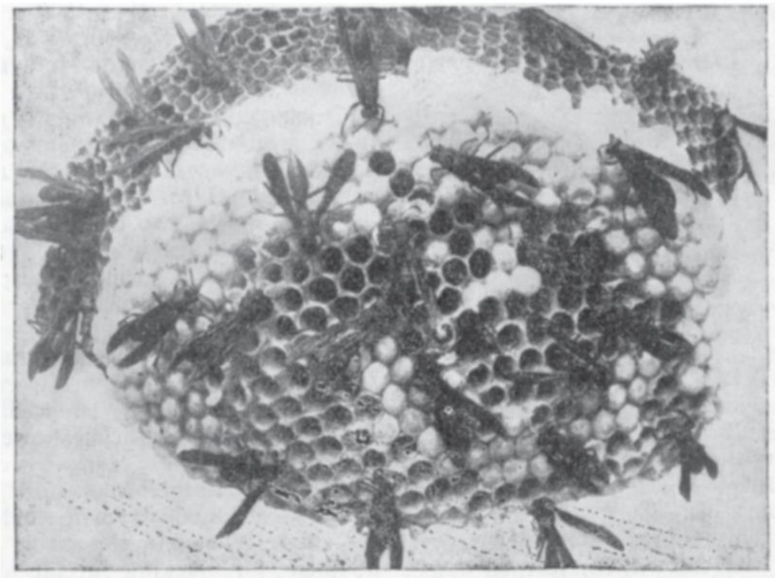
These are yellow or red insects with black markings and comprise social as well as solitary wasps. They usually have a long slender petiole and the forewings possess a very long first discoid cell. At rest the wings are usually folded longitudinally. Anal lobes are absent in hindwings. The conical sessile abdomen in the female has the ovipositor at its apex. Generally these insects are predaceous on caterpillars, which are paralysed by stinging, collected and stored in the cells of their nests. In each cell a number of larvae are stored and an egg is suspended by a filament from the top of the cell, which is sealed subsequently.

The wasps belonging to Vespinae, Polistinae and Polybiinae are social wasps and the rest are solitary wasps.

The social wasps include males, queens and workers. The latter two castes are females with a very effective sting. The papery nests of these social wasps are constructed out of chewed foliage or wood. In the temperate regions the colony lasts for a season. The queen overwinters and commences formation of a new colony in September. Initially in her first brood it raises the workers in the nest newly constructed or in a previously built nest. Thereafter, it devotes itself to egg-laying. The following subfamilies are important.

Subfamily *Vespinae (yellow jackets or hornets)*

The nest is made up of a number of circular combs attached one over the other and each comb contains numerous hexagonal paper cells. The whole nest is enclosed in a papery envelope. The nests are found in the open attached to branches of trees (Figs. 67.26 and 67.27). A few have their nests in the ground (Fig. 67.28). The larvae are fed upon by other insects, decayed or fresh meat and fish. The common Indian species are *Vespa orientalis, V. tropica, V. ducalis, V. basalis, V. cincta,* etc. In South India *V. cincta* is the most common species, which is often considered to be an enemy of the honeybee *Apis cerana.* Another species *Vespa tropica* var. *haemotoides* also attacks honeybee.



▲ **Fig. 67.26** *Waps and nests (Polistes annulans)*

▲ **Fig. 67.27** *Hornet's nest (Courtesy: USDA, Washington)*

Subfamily Polistinae

These are reddish or brown, slender and elongate insects with a spindle-shaped abdomen. The nest comprises of a single more or less circular, horizontal comb of paper cells. The nest is attached by a stalk to the support. The cells containing larvae are open but they are sealed once they pupate. *Polistes stigmata* and *P. hebraeus* are two Indian species.

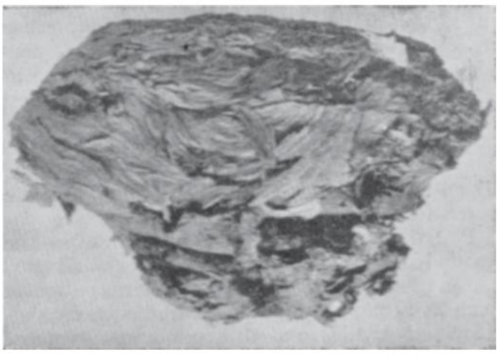
Subfamily *Polybiinae*

These are chiefly tropical wasps.

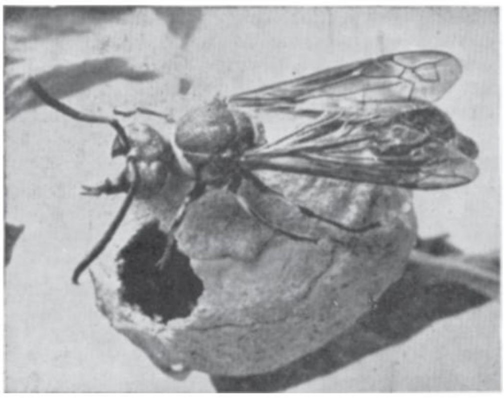
The members of other subfamilies, viz. Zethinae, Masarinae, Euparagiinae and Eurneninae, are called solitary wasps and of these Eumeninae are very common.

Subfamily *Eumeninae (mason or potter wasps)*

The wasps (Fig. 67.29) construct vase-like nests of mud, which are attached to twigs and other objects. Certain species have their nests in burrows in the ground. Tubular nests, divided into cells by mud wall, are constructed by some in wood or stems. A few make use of deserted wasp nest, or of key-holes or nail-holes. Small caterpillars, larvae of Tenthredinidae and chrysomelid bettles are stored in a cell. The egg is suspended by a filament from the roof of the cell and sealed. *Eumenes conicus*, *E. ensuriens*, *E. flavopicta* and *Odynerus punctum* are some of the Indian species



▲ **Fig. 67.28** *Underground paper nest of Vespula sp. (ibid)*



▲ **Fig. 67.29** *Potter wasp on cell (ibid)*

Superfamily SPHECOIDEA

Sphecoidea are characterised by the pronotum terminating laterally in a rounded lobe that does not reach the tegula. These solitary wasps are mostly fossorial and occasionally construct free mud-cells. They sting and paralyse caterpillars, bugs, genera of Orthoptera and Arachnida, etc. and carry them to their nests. Rarely are they parasitic on their allies. Some, which die due to stinging, do not decompose for several days. This includes the family Sphecidae. The following subfamilies are recognised.

Subfamily *Astatinae*

Varicolored wasps nest in the ground. The nests are provisioned with hemipterous insects, especially lygaeid and pentatomid bugs.

Subfamily *Larrinae*

Sand-loving wasps nest in burrows in sandy places. Spiders, small hemipterous insects, grasshoppers, crickets, etc. are provisioned in the nests. *Tachytes monetarius* and *T. erythropoda* are the two Indian species.

Subfamily *Trypoxyloninae (organ-pipe mud-daubers)*

The insects construct long tubular nests of mud and provision them with spiders. *Pison argentatum, Trypoxylon rejector* and *T. pileatum* are the three Indian species.

Subfamily *Pemphredoninae (aphid wasps)*

These nest in the ground or in cavities in twigs or logs and provision their nests with homopterous insects such as cercopids, aphids, membracids, cicadellids, and psyllids and thysanopterous nymphs.

Subfamily *Sphecinae (thread-waisted wasps)*

These nest in the ground and provision their nests with grasshoppers, crickets, cockroaches, caterpillars or spiders. *Ammophila humbertiana, A. laevigata, Sceliphron madraspatnam, S. violaceum, S. bilineatum, S. coromandelicum, Sphex lobatus, S. umbrosus* and *S. viduvatus* are some Indian species.

Subfamily *Philanthinae (digger wasps, bee-killer wasps)*

These provision their nests with bees, winged ants and beetles. *Cercerus instabilis* and *Philanthus ramakrishnae* are some Indian species; the latter is an enemy of *Apis cerana indica* in South India.

Subfamily *Crabroninae (digger wasps)*

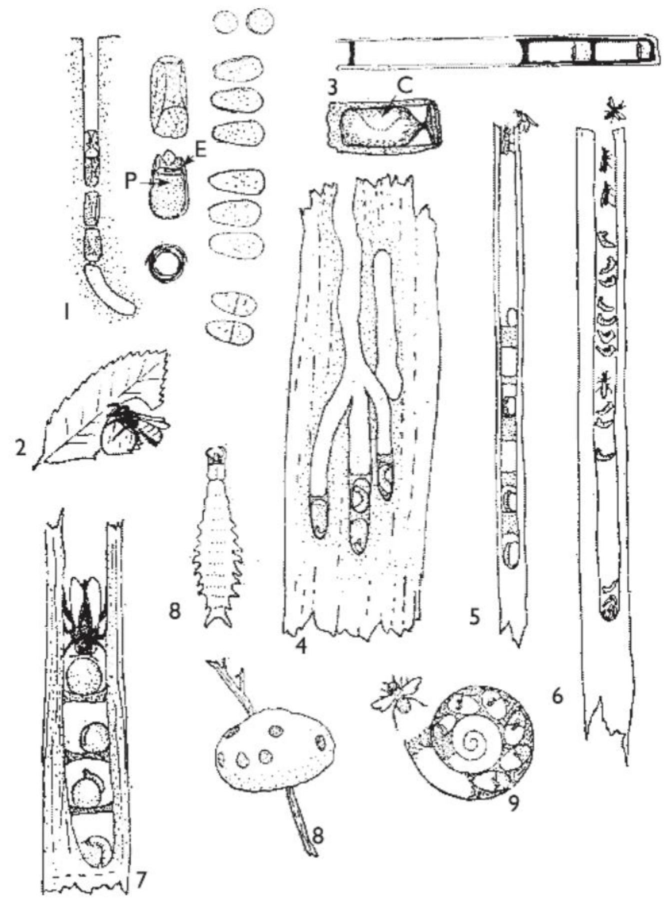
These nest in burrows in the ground, in hollow stems or in abandoned galleries in wood. They provision the nests with flies. *Oxybelus squamosus* and *Crabro orientalis* are the two Indian species. In Delhi, a species of *Crabro* has been reported to cause damage to freshly pruned rose plants.

Superfamily APOIDEA (BEES)

This superfamily includes the solitary and social bees, the latter being confined to the families Apidae and Halictidae. These are commonly found visiting flowers and aid in cross pollination of crops by carrying pollen, which adhere to their body hairs. The antennae are 13-segmented in male and 12-segmented in female. The mouthparts in most bees are adapted for sucking nectar from flowers. The structure of the tongue, formed of maxillae and labium, varies considerably in different bees and is of taxonomic importance. A pollen collecting apparatus is well developed in females which is situated either on the ventral side of the abdomen as in Megachilidae or on the hindlegs as in other bees. Bees, which are inquilines in the nests of other bees, do not possess the pollen collecting apparatus. The body hairs in bees are plumose or branched, which in the case of wasps are simple and unbranched. In males there are seven visible tergites in the abdomen as against six in the females.

Nectar and pollen form the food for the adult bees. The nectar is elaborated into honey in the crop of the bee. The larvae are fed by honey and pollen whereas in wasps animal material constitutes the larval food.

The solitary bees nest in burrows in the ground, in hollow stems, etc. and provision them with honey and pollen. The parasites or inquilines on the other hand lay their eggs in the nests of other bees and do not construct nests of their own. The social bees nest in comb-like subterranean excavations, in galleries in wood, in hollow cavities of trees in vertical combs, etc.



▲ **Fig. 67.30** *Items 1-9. Bees' nests built in or on various objects. 1.* Megachile vera *nest with four cells, detail of cell, longitudinal and cross sections of cell, and ten leaf pieces that formed a cell; 2.* Megachile *cutting leaf; 3. Nest of* Megachile flavipes *with two mud cells and detail of cell showing cocoon (c); 4. Nest of* Lithurgus *in wood; 5.* Pithitis *and 6.* Braunsapis *in stems; 7.* Xylocopa *in bamboo; 8. larva of cuckoo bee,* Triepeolus *showing large mandibles; 9. nests of* Osmia *in snail shell (S. W. T. Batra, Oriental Insects* ***11****: 289–324, 1977)*

The following families are recognised:

Family Colletidae (plasterer bees and yellow-faced bees)

Colletids are primitive apoids, which nest in the soil or in cavities in stem or wood.

Family Halictidae (mining bees)

Halictids are widely distributed, small to medium sized, often metallic bees, which are mostly solitary and some are social with well developed workers. They visit flowers. The antennal socket is connected with the fronto-clypeal area by a single suture. The submentum and mentum are wanting. The first sector of vein M on forewing is nearly always strongly curved. Usually prepectus is present and the post-scutellum is horizontal.

They nest on excavated comb-like subterranean burrows and the main burrow is usually vertical with lateral tunnels or branches. The bees may nest close together. In the social species the cells may radiate in various directions from the main burrow and its branches or the cells may be arranged in pairs or singly along the burrow. In the solitary species at the bottom of each burrow a cell cluster may be seen or the cells may be joined to the vertical burrow by long, curved horizontal laterals.

In the nests on of *Halictus* and *Andrena*, species of *Sphecodes* live as parasites or inquilines.

Some of the Indian halictine bees are *Halictus (Seladonia) vicinus, H. (Seladonia) lucidipennis, H. latisignatus, H. paris, Lasioglossum (Ctenonmia) albescens, L. (Ctenonmia) cattulum, L. (Ctenonmia) splendidulum, Lasioglossum (Evylaeus)* sp., *Nomioides variegata, N. minutissima, N. pusilla, N. divisa* and *Systropha punjabensis.*

Family Adrenidae (mining bees)

These are medium-sized solitary bees and gather pollen and nectar from flowers of a few species of plants. On the head below each antennal socket two subantennal sutures are present. These insects nest in the ground. The nest consists of a vertical tunnel with lateral branches ending in a single cell. Often they nest close together. In rare cases common entrance is used by several females. Many are parasitised by *Nomada* (Apidae) and Strepsiptera.

Family Melittidae

These are rather rare insects, small and dark-coloured and nest on the ground.

Family Megachilidae (leaf-cutting bees)

Megachilidae are moderate-sized, stout-bodied, densely haired, solitary bees. The presence of ventral scopa in the female (which is wanting in parasitic forms) and two submarginal cells of about equal size in forewings are characteristic features of this group. They nest on cavities in wood and occasionally in burrows in the soil and line with neatly cut out pieces of leaves. Some build nests with mud cells. A bee prepares a cell at a time and fills it with paste of honey and pollen and lays eggs on it. Some are parasitic.

These solitary bees are parasitised by bombyliids (*Leucospis* and *Stelis*).

In India, the leaf-cutting bee (*Megachile anthracina*) damages considerably pigeon pea, rose, etc. by cutting off circular bits of leaves from the plants. The other common species noticed are *Megachile disjuncta*, *M. lanata*, and *M. conjuncta*.

Family Apidae

A large number of solitary and parasitic bees and the social honeybees are included under this family. These insects are characterised by usually three submarginal cells in forewings. If two submarginal cells are present, the second cell will be much shorter. Rarely it may be single. The scopa is present, usually on the hindlegs and rarely on gastral sternites also.

Three subfamilies are recognised: the Anthophorinae, Xylocopinae, and Apinae.

Subfamily *Anthophorinae (mining or digger bees and cuckoo bees)*

Anthophorinae are characterised by somewhat protuberant clypeus and the presence of a triangular plate-like area in the last abdominal tergite. The cuckoo bees are usually wasp-like with very few hairs on the body and are parasitic. The others collect pollen. They nest on the ground or on barks.

Subfamily *Xylocopinae (carpenter bees)*

Xylocopinae are characterised by absence of protuberance on clypeus and a triangular plate-like area on the last abdominal tergite.

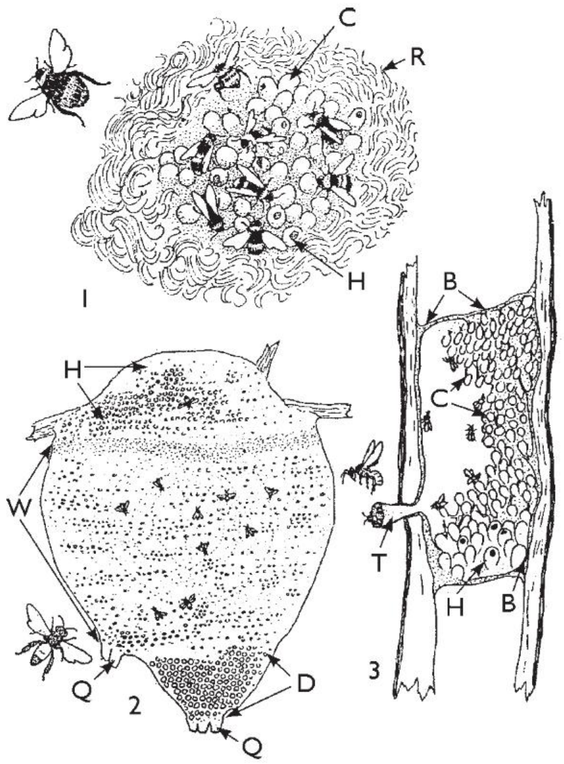
The small, dark bluish-green carpenter bees belonging to *Ceratina*, tunnel into the pith of stems of bushes and nest in them. In South India, *Ceratina binghami* and *Allodape parvula* nest in the stems of rose plants.

The large carpenter bees, *Xylocopa* spp., are robust insects with iridescent hyaline wings and the abdomen is usually bare dorsally. It nests on dead logs, live branches of trees, wooden rafters in houses, etc. The tunnels ramify in all directions, consisting of a number of cells. The common Indian species are *Xylocopa aestuans* and *X. iridipennis*; *X. aestuans* tunnel into branches of tea bushes. The grubs of the beetles *Eucorynus crassicornis* (Anthribidae) and *Horia debyi* are found in the nests of *X. aestuans* in India.

Subfamily *Apinae (social bees)*

Apinae includes the bumble- or humblebees and the honey bees. The role of these insects in the pollination of plants is remarkable. The honeybee *Apis cerana indica* is the domesticated bee and is an extremely valuable insect as it provides honey and beeswax in addition to its pollinating activities.

The bumble- or humblebees are relatively large, robust, generally black and yellow coloured insects, which nest in grounds (Fig. 67.31). The honey bees are golden-brown insects and are devoid of spurs on hind tibiae.



▲ **Fig. 67.31** *Nests of Apidae. 1. Bumblebees* (Bombus) *nesting in fibres of a rodent nest (R), C- brood cells, H- honey storage cells; 2.* Apis florea *comb on branch: H-honey storage cells, W- worker brood cells, D- drone brood cells, Q- queen cells; 3.* Trigona *nest in hollow log, showing entrance tube (T) with guards, B- batumen enclosure, H-honey pots, and C-brood* cells (ibid)

The typical honey bees that occur in India are *Apis dorsata* (rock bee), *Apis cerana indica* (Indian bee), *A. florea* (littlebee) (Figs 67.31 and 32), *A. mellifera* (Italian bee) and *Trigona iridipennis* (dammar bee) (Fig. 67.31). Datails of the above five species and apiculture are dealt with elsewhere in this book.

▲ **Fig. 67.32** *Apis florea worker*

Part 3

Applied Entomology

Section Seven

Productive Insects and Usefulness of Insects

◆ Chapter 68

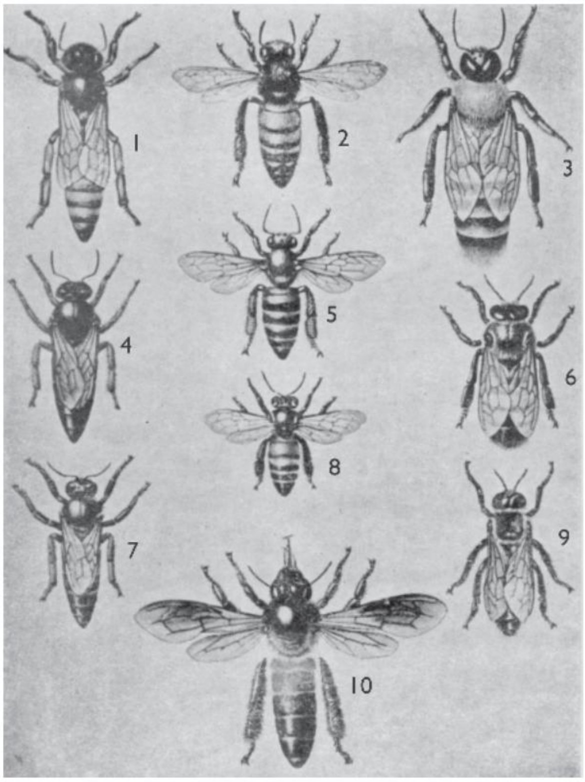
Apiculture

Applied Entomology generally connotes the study of insects injurious to man, livestock and crops, which have been dealt with under Part II. However, there are a number of insects, which are beneficial to man. A few important species of insects produce certain substances during the course of their life, which are appropriated by man for his own use. Beekeeping (apiculture) has been practised by man from very early times to gather honey and beeswax. Sericulture is a branch of technology, which is primarily insect-based, the various silkworms yielding silk fibres of commercial value. Sericulture involves rearing of silk worms, which are domesticated either completely or partly depending on the species, from which silk is extracted. Lac industry of India is exclusively the exploitation of the lac insect. Entomologists have neglected the study of the roles played by insects as pollinators. With the advent of biological control measures, insects have been used to fight insect menace. Though the damages done by insects outweigh the benefits of insects to mankind, it should be borne in mind that human ingenuity has exploited the services of these insects to a considerable extent.

Honey bees, silk worms and lac insects constitute the most important productive insects which are briefly mentioned here.

HONEY BEES provide man with nutrient rich honey and beeswax, besides playing an essential role in the pollination of crops many of which depend solely on them. The exploitation of bees as natural resources did not attract sufficient attention till the beginning of the 20th century, though a few attempts had been made to domesticate the different species of honey bees by the end of the 19th century. India has a wealth of bee species, some of which produce efficient crops of honey.

The five principal species of honey producing bees are *Apis cerana indica*, the Indian bee, *Apis dorsata*, the rock bee, *Apis florea*, the little bee, *Apis mellifera*, the Italian bee, (Fig. 68.1) and *Trigona iridipennis*, the dammar bee.



▲ **Fig. 68.1** *Indian Honey bees: 1-3 Apis mellifera Queen, Worker and Drone; 4-6 Apis cerana indica Queen, Worker and Drone; 7-9 Apis florea Queen, Worker and Drone; 10 Apis dorsata Worker (after C. C. Ghosh-from Textbook of Agricultural Entomology, H.S. Pruthi, 1969.)*

Apis dorsata is the biggest known honeybee in the world, usually confined to the forest-clad hills and in evergreen forest areas of the plains. The single comb it constructs is a very large one, 1.0 to 1.5 metre long, 0.5 to 1.0 metre wide and overhangs precipitous rocks or on inaccessible branches of trees. Temperamentally they are unfit for domestication even though they produce large amounts of honey ranging from 18 to 36 litres of honey depending upon the size of the colony. In the deep forests of South Andaman, crushed/

squeezed stems of *Amomum aculeatum* (Zingiberaceae) or sap of its flowers, or whole plant sap and leaf juice of *Zingiber squarresum* (Zingiberaceae) when rubbed on the body of the honey collector act as tranquilizer for the giant honey bee *A. dorsata.*

Apis cerana indica is a smaller-sized honey bee, which is domesticated in view of its mild temperament and non-migratory habit. It constructs several parallel combs inside cavities, generally in hollow trees. Its flight range is 600-1040 m.

Apis florea is a smaller-sized honeybee and constructs tiny single combs on twigs, crevices in buildings, bushes, etc. This species is unfit for domestication in view of its poor honey gathering capacity and migratory habit.

Apis mellifera is an introduced species and has been domesticated. It is performing better than the Indian bee and is replacing it in domestication in many parts of the country. Its flight range is 3-14 km.

Trigona iridipennis is a very small dark bee, which nests in crevices in walls, hollow trees, etc. Though they possess vestigial stings, they are known as "mosquito" or "stingless bees." They secrete wax, which is mixed with earth or resin and the resulting dark material is called "cerumen." The wax is secreted between the abdominal tergites of the workers. The cells, made of cerumen, are clustered irregularly. The group of cells is enclosed in batumen (a protective layer of plant resin or propolis and beeswax). The nest has 4-50 cm long, funnel-shaped waxen entrance tube edged with a sticky substance. The entrance is guarded during the day by workers and closed at night as protection against ants and other predators. Foragers communicate the location of food source to other workers by laying a scent trail and also by leading them to food. Honey and pollen are stored separately in dark-coloured globular cells and their tiny ellipsoid pellet-like brood cells are constructed individually. The honey produced by this species is only in very small quantities. In Coimbatore its reproduction occurred mostly during March to June. New colonies are started by swarms containing many workers and a queen.

History: The pot hive method of bee keeping utilising hollowed out trunks of trees or empty pots smeared with wax and sweet scented leaves of *Cinnamomum iners* inside, and kept in forests to attract bees, was practiced for quite some time in Mysore, Coorg, Kashmir, Malabar, etc. It was in 1907 that the scientific method of bee keeping commenced. Initially the apiaries were developed with hives bearing movable frames and with every passing year the number of apiaries increased. The period from 1875 to 1914 was the golden age of bee keeping since it was during this period that the industry was established on a solid foundation. Since then several modifications of hives have emerged such as the book hive, Madhusagar hive, house hive, nuclear hive, single walled Dadant hive, British standard hive, Langstroth hive, Jeolikote hive and Newton hive. Of these, the Newton hive is the most popular.

Apiculture has proved to be an important cottage industry. Apiaries are usually located at places where there is abundance of pollen and nectar-yielding plants within a radius of one kilometre. A young orchard with sufficient shade, less windy and with fresh running water appears ideally suited for the location of apiaries and may contain 50 – 100 colonies, placed two to three metres apart in rows.

The Indian honeybee *Apis cerana indica* and the Italian bee *Apis mellifera* are hived and reared in specially designed hives for its honey. A colony consists of the queen, the workers (sterile females) and the drones (males). In South India the period from November to May constitutes the breeding and honey flow season and the period from June to October is the slack season. The bees are usually most active in the collection of nectar and pollen at a temperature range of 25^o to 27^o C and relative humidity of 70 to 80%. Further, the honey yield is directly proportional to the availability of bee pasturage in a locality. The bee is capable of carrying pollen loads of 26 to 35 % of its body weight.

The females develop from fertilised eggs and the males as parthenotes. The queen after the nuptial flight stays in the old hive or in a new one and commences egg laying. It lays about 500 eggs per day singly in the hexagonal cells of the comb. The cells in the comb in the brood chamber in the lower part of the hive are reinforced with propolis and these constitute the brood cells. The cells in the combs in the super of the hive are made up of pure wax and honey is stored in these cells. The longevity of the queen is three years.

The grubs that hatch out from fertilised eggs are fed for a day with "royal jelly" and on bee-bread during the rest their life cycle as grubs. The royal jelly is a nutritious food rich in protein, 40–43 % by weight. It comprises of 15–18% proteins, 2–6.1% lipids, 9–18 % carbohydrates and 0.7–1.2% ash. The adults that develop from these give rise to workers. The development from egg to adult takes about 26 days and the worker bee lives for 45 to 80 days. These attend to indoor activities of the hive, such as cleaning the hive, nursing, building combs, etc. extending up to the first 13 days of their life, and thereafter devote to foraging activities. The grubs that hatch out from unfertilised eggs are fed with royal jelly for the first three days and with a mixture of royal jelly and bee-bread until they pupate. These develop into males. The development period is about 23 days and it lives for about 60 days. They develop in large numbers only in certain seasons. The cells in which the workers develop are smaller, numbering about six per sq. cm. In certain seasons a few special cells of larger size are constructed at the lower part of the hive and the grubs that hatch out from the fertilised eggs laid in these cells are fed with royal jelly throughout and they develop into queens.

By the beginning of the honey season when the population of a colony has sufficiently increased, swarming takes place in which the ruling queen and a part of the population of bees move away. The group thus emigrated in a mass is collectively known as a "swarm".

Swarming in bees helps in the dispersal of the species. A preponderance of drones in the brood is the first symptom. After a fairly large number of drones have emerged and many more are under rearing, a number of queen cells are constructed along the lower border of the brood combs and a fertilised egg is laid in each. By the time the inmates attain the pupal stage the reigning queen and a large proportion of workers swarm out and establish elsewhere. This is the "prime swarm". Now the new queens emerge. If the population is sufficiently strong at the stage when a new queen emerges, she goes out and this process goes on, until the strength of the parent colony is reduced to the minimum. If a number of queens emerge at a time and swarm out only one survives. When the colony becomes too weak to send out any further swarms the emerging queen kills all her rivals by biting and destroying other queen cells in the hive. To ensure a regular crop of honey, a bee colony should possess a significant number of individuals as workers and the yield of honey is directly proportional to the hive populations. In a thriving colony the bee population is estimated to be 26,300 to 35,700 and this strength is needed for storing up surplus honey. Local weather conditions play a vital role in influencing fluctuations of the bee number and hence in the amount of honey yield. Barring slight variations, there appears to be two main seasons: a slack season between June and October and a honey flow season from November to May.

It is also known that bees show certain amount of discrimination in visiting plant species for gathering honey. Available information on the bee pasturage plants indicates that among the pollen yielders, maize (*Zea mays*), and jowar (*Sorghum vulgare*), are the best, followed by pearl millet (*Pennisetum typhoideum*), castor (*Ricinus communis*), coconut (*Cocos nucifera*) and *Peltaphorum ferrugineum*. Of the nectar-bearing plants, cotton (*Gossypium* sp.), *Gliricidia maculata*, tamarind (*Tamarindus indicus*), neem (*Azadirachta indica*) and banana (*Musa paradisiaca*) are outstanding. The quantity of pollen collected by a bee per trip is on an average 0.025 g. The Indian bee is said to be capable of carrying pollen loads of 26.35 % of its body weight and compares very favourably with the European bees. The maximum quantity of nectar collected by a bee per trip is about 0.00323 g. During the lean periods, in order to sustain honey production in apiaries and to stimulate brood rearing and increase in the population, artificial feeding on dilute honey and sugar syrup is resorted to in the case of bees like *A. mellifera*.

The taste and colour of honey varies according to the source of the plants from which nectar is collected. It is light coloured with mild flavour from soapnut trees; yellow from mustard; dark amber coloured with strong flavour from *Dalbergia*; strong unpleasant odour from *Polygonum*. Honey in the prosperous season is extracted once in ten days, the annual yield varying with localities.

The role of bees in pollination is well known. Setting of fruits and seeds and increase in crop yields need no citation to highlight the parts played by the bees. The importance of bees in pollination in cotton and sunflower needs no mention.

A few natural enemies present serious problems in apiculture. They are the greater wax-moth *Galleria mellonella* and the lesser wax-moths (*Achroia grissella* and *A. innotata lankella*. The other bee enemies include the wasps *Palarus orietnalis, Vespa cincta* and *V. tropica* var. *haematoides*, the reduviid bug *Acanthaspis siva*, the tenebrionid beetle *Platybolium alvearium*, the black ant *Camponotus compressus*, the death's head moth *Acherontia styx,* the leaf cutter bee *Megachile disjuncta*, cockroaches, the arachnid *Ellingsenius indicus*, lizards and the birds *Dicrurus ater* (drongo) and *Merops viridis* (bee-eater).

The ectoparasitic mite *Tropilaelaps clareae* occurs throughout the year in colonies of *A. mellifera,* being serious during March-April and October-November in the Punjab. Dusting with sulphur on the top of bars inside the beehives at 1 g/frame gives significant mortality of the mite and application would be needed at fortnightly interval. The ectoparasitic mite, *Varroa jacobsonsi,* infects *A. mellifera* in Delhi, Punjab, U.P., Karnataka and Kerala. The endoparasitic tracheal mite, *Acarapis woodi,* is prevalent on both the species of honey bees in Kashmir, H.P., Uttar Pradesh and Punjab.

The honey bee diseases caused by an iridescent virus and the Thai sacbrood disease by a virus, the American foulbrood by *Bacillus larvae* are important.

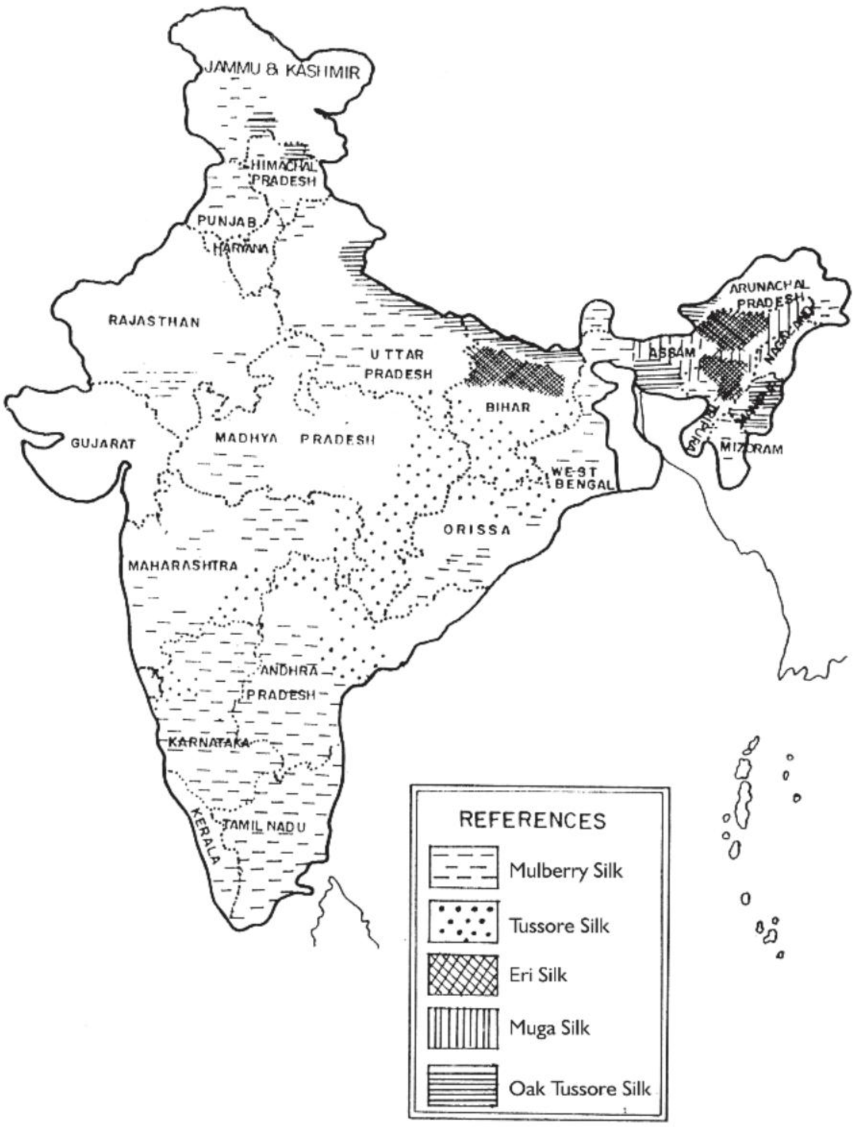
◆ Chapter 69

Sericulture

Since time immemorial, silk has become an inseparable part of Indian art and culture, and is a labour-intensive and agro-based industry. Sericulture plays a vital role in the rural economy of this country. Although it was China, which had the credit of discovering silk, it was kept secret for centuries. India now occupies a unique position in the world for being the only country with its rich sericigenous fauna to produce pure mulberry silk as well as all the three varieties of non-mulberry silks, i.e., Tasar, Eri and Muga silk. Of the latter varieties, India holds the world monopoly so far as Muga silk is concerned and it is particularly produced in various areas in and around Assam.

Pure silk is produced by *Bombyx mori* on mulberry leaves, while the other varieties of silk are produced by *Antheraea mylitta, A. assamensis* and *Samia cynthia*, yielding Tasar, Muga and Eri silks respectively. Besides these the hybrid strain produced as a result of cross-breeding of a Chinese species *Antheraea pernyi* with *A. proylei*, produces Oak Tasar silk.

From the point of view of silk-yielding potential as early as 1909 Lefroy recorded as many as 26 species of Lepidoptera producing silk. Of these some of the more important and well known species are the Indian moon moths *Actias selene, Sonthonnaxia maenas, Proctias sinensis*; the great Indian atlas moth *Attacus atlas* producing "Fagara silk" and *Archaeoattacus edwardsi.* The wild tasar moths include *Antheraea affrithi, A. helferi, A. knyvetti, Cricula trifenestrata, Leopa katinka* and *Rhodinia newara.* These species do not appear to be viable for exploitation. The biology of the principal silk producing species, the mulberry silkworm, exploited for commercial purpose, is briefly mentioned here. The silk producing regions of India are depicted in Fig. 69.1.

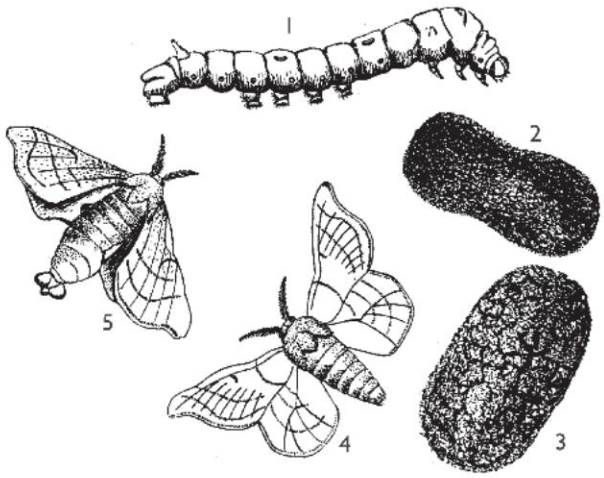


▲ **Fig. 69.1** *Map of India showing silk producing regions (Courtesy: Annapurna Dhal, 2000)*

1. The Mulberry Silkworm *Bombyx mori*

Silk is produced by the completely domesticated bombycid species, *Bombyx mori* (Fig. 69.2). It feeds only on mulberry leaves. It is distributed mainly in the areas of Assam, Bengal Bihar, Orissa, Madhya Pradesh, Maharashtra, Karnataka and Jammu and Kashmir.

Being domesticated, *Bombyx mori* can conveniently be reared under controlled conditions up to their cocoon formation, which is not allowed outdoors for various reasons. The species is either uni-, bi-, or multivoltine and depends on the number of generations per year. Univoltine races occur in Europe, Kashmir and the Punjab, multivoltines occurring in South India, Assam and Bengal. But from the quality point of view, the uni- as well as bivoltine forms appear much better than the multivoltines. Silk is produced by the labial glands that are enlarged anteriorly into a reservoir, which is produced into a duct, the two ducts on each side converging into a spinneret. The viscous secretion of the glands, on contact with air, hardens to form a fine thread, the silk. Silk consists of 75 % fibroin, a tough elastic protein and 25 % gelatinous protein, siricin. Fibroin is the inner layer, and siricin, the outer. A single caterpillar produces 650 – 1300 meters of silk thread. Mulberry trees flourish well for 10 – 12 years and every year six to eight crops of leaves are harvested, yielding 25 – 30 metric tonnes of green leaves. About 50 – 62 % of the silk in the cocoon is reelable and forms the raw silk, the rest being waste silk. Estimates indicate that 60,000 cocoons yield a kilogram of raw silk, requiring about a ton of mulberry leaves.



▲ **Fig. 69.2** *The Mulberry silkworm stages: 1. Larva, 2 & 3. Cocoons, 4 & 5. Moths (from Indian Museum Notes)*

Adult moths are creamy in colour, about 2.5 cm long, living for two or three days after emergence from cocoons. Mating occurs soon after emergence, each female laying 300 – 400 brownish white, seed-like eggs in masses. Eggs hatch in 8– 12 days, the caterpillars feeding on mulberry leaves and moulting four times. The full-grown caterpillar is about 5 cm long, the larval period extending from 28–30 days. Prior to pupation, a long, continuous strand of silk is spun to form an oval cocoon, prepupation taking place within the cocoon and the adult emerging in 10 – 12 days. It takes about six to eight weeks to complete the life cycle. The adults are incapable of active flight.

Silkworm Races The Central Silk Board (CSB) has brought out a system of 'authorisation of silkworm races'. Test rearings are done twice a year at 14 centres in the country and silkworm hybrids authorised by CSB are exploited commercially in sericulture. Mulberry silkworm hybrids for different states such as Andhra Pradesh, Assam, Bihar, Madhya Pradesh, Orissa, West Bengal, Jammu & Kashmir and Uttar Pradesh have been identified. In India, over 95% of commercial silk being produced is from multivoltine female × bivoltine male parent (cross breed). The hybrid BL23 x NB4D2 is meant for rainfed areas in Karnataka and BL24 × NB4D2 is for irrigated areas in all seasons. Rearing package for the above has been developed by the Central Sericultural Research & Training Institute, Mysore (CSR & TI).

The CSR & TI, Mysore initiated breeding work for production of quality silk utilising two Japanese commercial hybrids, which resulted in the evolution of highly productive CSR breeds. The CSR races authorised by CSB for commercial exploitation include CSR 2, 3, 4, 5, 6,12, 16, 17, 18 and 19. Similarly with emphasis on robustness KSSRDI, Bangalore evolved two races viz., KSO1 and SP2, which were bred utilising South Koran, Taiwanese bivoltine, NB4D2 and Pure Mysore races adopting hybridisation and selection method. The hybrids KSO1 × SP2 and SP2 × KSO1 proved to be better hybrids in respect of hybrid vigour, robustness and productivity.

Sericulture Successful sericulture depends on quality silkworm eggs. It is important that the grainage room and implements are disinfected and kept ready to receive seed cocoons. The seed cocoons, free from disease, are to be packed loosely, either in perforated plastic crates or bamboo baskets, and transported to respective destinations during cooler hours of the day. Immediately after receipt, the seed cocoons are to be spread on trays in a single layer and unhealthy or spoilt cocoons, if any, should be removed and discarded. The healthy cocoons are preserved in a room at 25 ± 1°C temperature, 75 ± 5% R. H., and 12 hours light and 12 hours dark conditions. Complete darkness is to be maintained on the previous day of emergence, to avoid irregular emergence of moths.

After 1-2 hours of emergence, the male and female moths are allowed to pair for 3.5 to 4 hours of pairing and then depaired by moving side ways without injuring the reproductive organs. The mated females are then taken in a separate container and induced for urination. They are placed on egg sheet and covered with cellules and kept in dark condition for oviposition.

Washing of eggs in formalin solution helps in firm adherence of eggs to the sheet and sterilises the eggs. The eggs are subjected to ideal condition of incubation viz., 75 ± 5% R. H., 25 ± 1°C temperature, 16 hours light and 8 hours darkness. Loose egg preparation method is also being practiced and loose eggs are preferred due to uniform egg number, increased egg recovery and easy and better management. Starched sheets are prepared and spread in the oviposition tray and female moths at 40-50 (bivoltine) or 50-60 (multivoltine) per sq. ft. are allowed for oviposition. The sheets are soaked in water for 20-30 minutes and the eggs are gently dislodged and collected into nylon mesh bags. They are dried by switching on the fan. In the case of bivoltine eggs acid treatment is done, washed, then dried and packed. In South India, multivoltine, pure multi-bivoltine, bivoltine pure and bivoltine hybrid silkworm eggs are used for silkworm rearing.

The development of multivoltine and multi-bivoltine embryo is a continuous process and after oviposition, the eggs hatch out within 10 days. If hatching is required to be postponed it can be done by refrigeration/cold storing methods.

Silkworm Rearing Silkworm eggs are to be handled with care during transportation. It is ideal to transport eggs on the second or the third day of oviposition during the cooler hours, packed in a bag made of rigid plastic mesh lined inside with thin foam. This is again placed in a card board box with thermacol lining and a wet foam pad to maintain humidity and aeration. Appliances/devices/methods such as BOD incubators, spreading of eggs on a clean and disinfected wax paper surrounded by wet foam pads, earthen pots or double walled chambers have been developed and recommended for egg incubation. The core activity of sericulture industry is production of quality cocoons in appreciable quantity. Factors which influence these are leaf yield (12–15 kg required for rearing a hybrid), selection of races/combinations, rearing house with an ante room to prevent Uzi fly, a separate chawki rearing building, etc.

Transfer of the newly hatched larvae from eggs on to the wax paper or rearing bed is known as "brushing". In a 4' × 3' tray, 50 dfls (disease free layings) can be brushed and reared up to first moult and 25 dfls up to second moult. The egg sheets are distributed in required number per tray before hatching. Fresh, tender and succulent mulberry leaves (with 80–85% moisture) from a well maintained garden are collected and chopped to 0.5 – 1.0 cm^2 and spread over the hatched larvae on to the egg cards. After 30 minutes, when all the worms have crawled on to the leaf, the leaves along with the worms are transferred on to the wax paper on a rearing tray with the help of a soft feather and arranged in the form of a thin bed. Clean wet foam pads are kept around the rearing bed and covered with a paraffin paper to maintain the humidity. The trays are piled one above the other in the form of a box to conserve leaf moisture for a longer period.

In the case of loose eggs two layers of cotton/nylon net is spread over them. On hatching, chopped leaves are spread over the net. After an hour, the worms along with the top net are lifted and brushed in a chawki tray.

Rearing of young age silkworm up to second moult is called “chawki rearing”, which usually lasts up to 10 days. Under optimum rearing conditions, the worms take 3 to 3½ days to settle for first and third moult, and 2 to 2½ days for second moult. At the end of fifth stage i.e. on sixth or seventh day, larvae reduce leaf consumption, release wet faecal matter, shrink in size, body becomes translucent and start crawling with raised head on the bed. Such larvae are collected and mounted on bamboo or other types of mountages. Temperature of 24°C, humidity of 60–65% and good aeration are ideal for spinning. The cocoons are harvested on the fifth day or sixth day after spinning. Double cocoons and flimsy cocoons are discarded and cleaned cocoons are marketed.

Stifling of Cocoons Partial drying of cocoon with 75 to 80 % drying is suggested instead of steam stifling. Open pan cooking method has been developed by CSR & TI.

Silk Reeling It aims at extraction of silk filament from cocoons. Silk is produced mainly by using three reeling technologies viz. charka, cottage basin/domestic basin and multi-end technology. Re-reeling is done to transfer the raw silk reeled on small reels to a large reel (1.5 m circumference) to set uniform width, weight and length of the skein. It is followed by silk finishing: lacing and silk skeining, book making (2 kg books) and long skeining and long book making (5 kg books). Each book is packed with paper and polythene to protect raw silk from damages by moisture and insects.

Sericultural Diseases Pebrine caused by a microsporidian, *Nosema bombycis*, is a chronic disease in silkworm, being transmitted to off spring by transovarial transmission from mother moth. Silkworm gets infected while feeding on contaminated mulberry leaves and from surface contaminated eggs. Disinfection of seed production unit, appliances, silkworm rearing house surroundings and silkworm egg surface are suggested.

Grasserie, also known as Haluthonde, is caused by nuclear polyhedrosis virus, a baculovirus. Disinfection as suggested above prevents infection. In addition, in case of high incidence of disease, spray 0.3% slaked lime solution in rearing house and appliances.

Flatcherie is a syndrome associated with infectious Flatcherie, Densonucleosis, cytoplasmic polyhedrosis, bacterial diseases, and *Thatte roga* in silkworm. It may be caused by these viruses individually as well as in association or each in association with Streptococci and Staphylococci bacteria (*Thatte roga*). Preventive measures suggested above can be followed.

Muscardine is caused by *Beauveria bassiana* and Aspergillosis by *Aspergillus flavus, A. oryzae* and *A. tameri*. Formalin 3%/bleaching powder 2% in 0.3% slaked lime solution is suggested for disinfection of rearing houses, appliances and even surroundings.

Silkworm Parasitoid The Uzi fly, *Exorista bombycis,* (Tachinidae) causes 10-20% loss to sericulture industry and occurs severely during July-November, though prevalent throughout the year. It is an endo-larval parasitoid. A female fly lays about 300 eggs at the rate of one to two eggs on each silkworm larva. The eggs hatch in two to three days and the larva enters into the body of the host and feeds on the tissues for five to eight days. It then comes out of the body of the silkworm larva and after 12–20 hours pupates in loose soil or crevice on the rearing house floor, etc. The adult fly emerges in 10–12 days. The total life cycle takes 18–24 days.

Management Infested silkworm larvae and Uzi fly larvae and puparia are collected and destroyed. Uzi infested silkworm larvae pupate one or two days earlier than the healthy ones and they should be collected and destroyed. Prevention of entry of Uzi fly is suggested by putting up nylon net to doors, windows and ventilators of the rearing house with an ante room at the entrance to the building. Uzi trap (a chemotrap) effectively traps and kills the adult flies. It is a tablet weighing 2.5 g, which is dissolved in one litre of water and kept near windows of rearing houses commencing from third instar till the spinning stage of silkworm. Uzicide, is an ovicide, available in liquid and powder forms. It is sprayed or dusted on the body of silkworms starting from second day in third instar through fourth or sixth day in five instar on alternate days except during the period of moulting. Release of an indigenous hymenopteran ecto-pupal parasitoid *Nesolynx thymus* kills the puparia of the fly.

Pests of silkworm in grainages Dermestid beetle, *Dermestes ater* DeGeer (Dermestidae) and earwig *Labia arachidis* (Yersin) (Labiidae) cause considerable loss in grainages. The dermestid grubs are controlled by dusting bleaching powder (30% chlorine) at 200 g/sq. ft. on the floor near the wall. The gunny bags/cotton bags used for storing cocoons must be dipped in 0.028% deltamethrin emulsion and shade dried. This can also be sprayed on floors and walls of cocoon storage rooms. Pierced cocoons before storage can be dusted with malathion 5% dust at 1kg dust / 10 kg cocoons. Wooden trays must be dipped in DDVP 0.076% solution, washed after 10 days, sun dried and reused. DDVP 0.076% spray can be applied on stands and storage room.

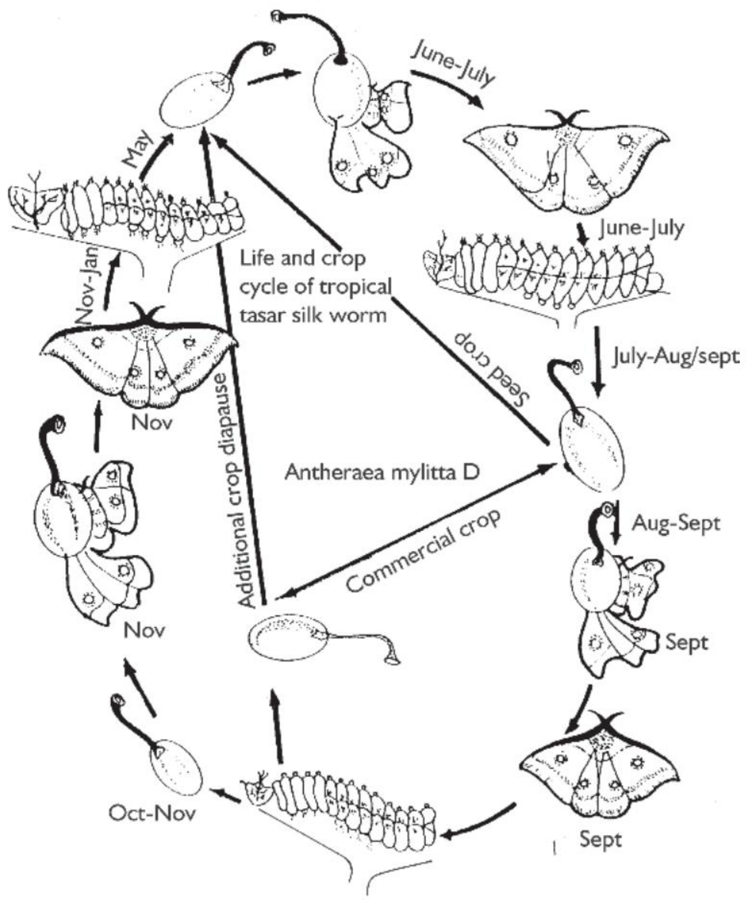
2. The Tropical Tasar Silkworm *Antheraea mylitta* Drury and The Wild Tasar Silkworm *A. paphia Linn.*

India occupies the second position in the production of tasar silk, being next only to China. At present 0.56 million hectares of forest is covered with tasar silk production while an estimated 11.6 million hectares have been identified as suitable for cultivating tasar silkworms. The tasar silk insect is found in wild and semi-domesticated condition and 25 ecoraces have been grouped depending upon their commercial characters and place of availability. The silkworms are polyphagous, generally feeding on *Shorea robusta* (Sal), *Terminalia alata* (Asan), *T. arjuna* (Arjun), *Zizyphus mauritiana* (Ber), *Lagerstroemia flosreginae* (Jarul/Patoli), *L. indica* (Saoni), *L. parviflora* (Sidha) and Hardwickia binata (Arjun), which are the primary food plants. Although colour of the silk cocoons is not affected by food, those cultivated on Sal appears to be superior to those grown on Asan or Arjun. The tasar silkworms are uni-, bi- or trivoltine and are found mainly in areas of Bihar, Orissa and Madhya Pradesh and in some parts of Maharashtra and Andhra Pradesh.

The wild tasar silkworm found in Orissa is *A. paphia* and when it occurs at high altitude (601-1000 m ASL) is known as *Modal*, the silk from cocoons having more economic traits. It is univoltine. When it occurs at low altitude (50 - 300 m ASL) is referred as *Bogei* and the cocoons produce silk of less economic traits. It may be bivoltine or trivoltine. The one occurring at mid altitude (310-600 m ASL) is known as *Nalia*, being bivoltine. Its first generation is semi-domesticated.

Antheraea mylitta is polyphagous and domesticated, feeding on leaves of Asan, Arjun and Sal. Most of the ecoraces are bivoltine and trivoltine. The ecoraces in Orissa are known as *Sukinda, Daba, Modal* and *Bogei.* Depending upon the voltinism of the race, the reproduction coincides with rain (July-August), autumn (September-October), and winter (November-December) seasons (Fig. 69.3). In Orissa *A. mylitta* is reared on Asan and Arjun plants and exhibits bi- and trivoltinism in two ecoraces such as *Daba* and *Sukinda*, respectively. *A. mylitta* grown in mid altitude is known as *Daba* and that of the low altitude is *Sukinda.*

The Oak tasar silk worm is the temperate silkworm represented by *Antheraea yamamai*, *A. proylei* and *A. pernyi* respectively, in Japan, India and China.



▲ **Fig. 69.3** *Life history of Tasar silkmoth (Voltinism) (Courtesy: Annapurna Dhal)*

Biology of Tasar Silkworms

Eggs are laid on tender leaves of the host trees and a moth lays about 200 eggs. The egg is creamy in colour, large, oval, flattened, and bilaterally symmetrical along the antero-posterior axis. The incubation period is 8–10 days. The eggs are glued firmly to one another and to the surface of deposition. The average weight of first day egg is 10.34 mg and that of sixth day egg is 9.23 mg.

The larva is greenish, elongated, cylindrical being flattened ventrally with red spiracles, robust, hairy and clothed with numerous tubercles, and the head being brown with bright ornamentations. Rarely may one come across blue, yellow and almond coloured larvae. There are five larval instars. On an average the grown up larva measures 11.30 cm long, 1.98 cm in girth and weighs 25.18 grams. The larval period takes about 35-70 days.

The grown-up larva pupates in a cocoon, which is oval shaped, closed, single shelled and light with a peduncle. The cocoons exhibit different colour types such as grey, black, yellow, greyish black, yellowish black, cream and creamy white. There are four different phases in cocoon construction, the first being nest formation, wherein the larva selects a twig and then forms a small nest or *hammock* by binding together the leaves with silk gland secretion through mouth. Then the larva comes out of the *hammock* and straps the bark 2–3 mm wide around the twig in the form of a ring. Simultaneously it initiates the peduncle formation by connecting the ring to the loop of the *hammock* with the help of few strands of silk. This process takes about 10 hours.

After *hammock*, ring and peduncle are ready, construction of cocoon proper is commenced. The larva gets itself enclosed in the cocoon made of silk and the cocoon formation takes two to three days. It then pupates inside the cocoon. The average dimension of male and female cocoon is 5.1 cm × 2.9 cm and 5.5 cm × 3.3 cm, respectively. The peduncle length in female is 5.7 cm and in male 4.0 cm. The volume of the cocoon is 28.6 cc in male and 29.5 cc in female. Normally a tasar cocoon is closed, single shelled and unipedunculate with a single pupa inside. The loop at the distal end of the peduncle helps in the cocoon being suspended firmly from the twig. Sometimes a cocoon may enclose two or three pupae and may also have more than a single peduncle. Though usually the cocoon is unishelled or monoshellate in nature, rare combination of two (bishellate), three (trishellate) and more (multishellate) cocoon shells may be noticed and are referred to as jointed cocoons. Cocoons should be harvested after six or seven days of formation. The branches are cut and the cocoons are pulled off the twig by breaking it near the ring. The pupal period ranges from 25 to 50 days.

The silk is reelable for which the pupae are to be killed before emergence of the moth, to prevent cutting of the silk thread into pieces.

The adult moth is large and beautiful. The male is brown coloured having slightly wider wing expanse than the brick-red moths. The female sepia or yellow coloured moth has widest forewing expanse whereas pink coloured moth has the shortest wing expanse. The body colour of female varies from cadmium, yellow through pinkish or brown.

Rearing

Rearing of domesticated variety is easier in comparison to wild variety. The traditional tasar rearers usually utilise thick patches of food plants of 3.0 to 3.5 m tall. It is important that same bushes are not used for two successive crops of silk in a year.

The establishment of healthier eggs of tasar silkmoths for production is very important and this is known as *grainage* (French: *Graine*-seed). The selection and preservation of seed cocoons, preparation of disease free layings and their disinfection and incubation are important aspects of grainage.

Well-formed, healthy and tough cocoons are selected after harvesting for seed purpose. The rearers purchase seed cocoons or produce their own seed. The Central Tasar Research and Training Institute, Ranchi maintains the nucleus tasar seed stock, which is supplied to its parental seed station and then to different Basic Seed Multiplication and Training Centres. These centres produce the basic seed and supply to the Pilot Project Centres of the states. This ensures supply of select good quality and disease free seeds. The seed cocoons procured should have at least 5-10 days for emergence.

If transportation of seed cocoons is involved, they are packed lossely in bamboo baskets or synthetic boxes or any perforated boxes in small quantities and transported during the cooler hours of the day or in the midnight to avoid damage due to high temperature. Cocoons are transported during diapause preferably in December-January. In the grainage room as soon as the cocoons are received they are hung in the form of garland with the help of peduncles.

The cocoons harvested out of the second crop, in case of bivoltine and trivoltine forms, enter into diapause from later part of August to later part of May, and in bivoltine and trivoltine of third crop from November to later part of May and from January to later part of May respectively. The optimum condition for preservation of seed cocoon is 25°C and 45-48 % relative humidity (RH).

Emergence of moths from the disapausing pupae commence with the onset of monsoon. The moths from the cocoons of the first crop (July) usually emerge during August-September, while those of trivoltine second crop emerge during later October, and of third crop during early November. Most of the moths emerge from the peduncle portion.

Mating takes place after three hours of emergence, the peak period being from midnight to 2 A.M. Mating may be carried out in captivity using bamboo baskets or manually and in outdoor conditions also. In outdoor mating the females are kept on the bushes during early evening hours and then the males are released. The mated pairs are collected early in the morning and kept in specially made earthen cups or card board or plastic boxes disinfected. Though egg laying lasts for seven days, the eggs laid in batches of 5-10 eggs up to three days are used for rearing. In a commercial grainage five moths are kept together for egg laying. After the third day of egg laying the moths are examined for perbrine, viral and bacterial diseases and the eggs laid by diseased moths are discarded. The eggs of healthy moths are termed Dfls (disease free layings) or certified eggs.

The eggs are disinfected with 5 % formalin solution for 5 minutes, washed with distilled water, shade dried by spreading over blotting paper, and then kept in laying boxes for incubation.

The eggs are transported within six days of oviposition in small bags of muslin cloth of size 22.5 cm × 10 cm, which may accommodate 100 Dfls and then put in perforated plastic or bamboo baskets.

The egg boxes are placed in a room for incubation and incubated at 28° – 30°C and 72-80 % RH. The hatching of eggs commences on the seventh or eighth day and gets completed in two or three days.

After the larvae hatch out from the eggs, the placing of larvae on the leaves of host plants is very vital. Traditionally leaf cups containing eggs are tied on to the bushes, or freshly emerged larvae are brushed on to the foliage of host plants. Out door rearing causes heavy mortality of first instar larvae.

Controlled rearing techniques have been developed and are being followed. The larvae are reared indoors until the first moult. The second instar larvae are allowed to crawl on to fresh twigs and then transferred outdoors. The development of economic plantation of tropical food plants of tasar has promoted the concept of early instar controlled rearing. Rearing up to third instar is done on economic plantations preferably under nylon netting. Once the larvae pass their second or third moult the twigs are cut and transferred to forest or block plantations for rearing to advanced stages. Nearly 4000 Dfls can be reared up to third instar on one hectare of economic plantations.

Diseases of Tasar Silkworms

In each season of rearing the larvae suffer from four types of diseases viz., pebrine (*microsporidiois*), polyhedral viral, bacterial and fungal diseases.

The Tasar Uzi fly *Blepharipa zebina* (Tachinidae) is parasitic on Muga and Tasar silkworms and cause loss of 30–40 % in silk yield. Other natural enemies of Tasar silkworm include *Xanthopimpla punctata* (Ichneumonidae), *Eocanthecona furcellata* (Pentatomidae). *Scanus collaris* (Reduviidae) and the mantis *Hirodulla bipapilla* (Mantidae).

3. The Muga Silkworm *Antheraea assamensis*

The Muga silk moth is restricted to the north-eastern states, particularly Assam, which holds monopoly in Muga silk production. The species is semi-domesticated and multivoltine, producing as many as five to six broods in a year. Though it feeds mainly on

Som (*Machilus bombycina*) and Soalu (*Litsaea polyantha*), the species is reported to be polyphagous feeding on as many as 18 hosts. As a result the colour of the cocoons and the quality of silk is considerably changed.

Although diapause is wanting in this species, the period of the life cycle may prolong from nearly one and a half months in summer to about three months in winter. The larvae on hatching are yellowish, but as they grow they turn to translucent green. On maturity the larvae move to the tree trunk early morning for cocoon formation, and thus can be easily collected unlike the *Antheraea mylitta*. The cocoons are light to deep brown, but white is not uncommon. Males are reddish pink, females lighter.

4. The Eri Silkworm *Samia cynthia ricini*

The Eri silk moth, also known as *Ailanthus, Endi, Errandi* silk moth, is economically important. It produces four to six crops in a year and is domesticated and mainly reared on castor (*Ricinus communis*) though it has about 29 hosts. On castor it takes about 20 days to complete the larval period. A hectare of castor yields 500,000 cocoons resulting in 250 kg of empty cocoons for silk production and 1250 kg of dead pupae. Besides the castor crop yields about 750 kg of seeds for oil extraction. The dead pupae are either consumed by local tribes, or are dried and powdered and used as feed for poultry, pigs or fish.

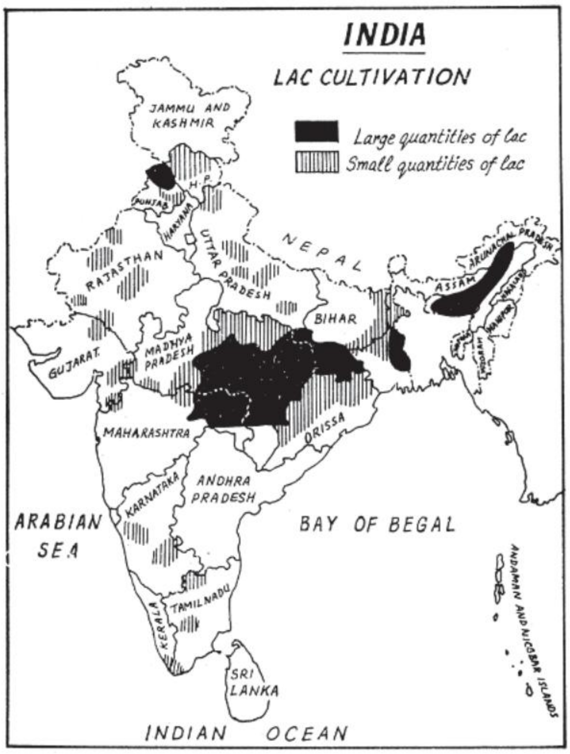
Depending on temperature the life cycle may take about one and a half to two and a half months. The eggs are oval and grey. The full grown larva is cream yellow, green or blue with prominent markings, which may be single or double dots, semi-zebra, zebra, etc. and 10 cm long. The adults are beautiful, predominantly brownish or yellowish brown. There are several sub species but *ricini* is a domesticated race since it is not easily separable from *cynthia*. The species is widely distributed, particularly in Assam, West Bengal, Bihar and Orissa, where it is exploited for the commercial production of silk. It is also known to occur in Himachal Pradesh and Uttar Pradesh.

Twenty eight grams of eggs will give about 1600 larvae which can yield 4 kg of silk after consuming leaves from about 0.5 hectare of castor crop.

◆ Chapter 70

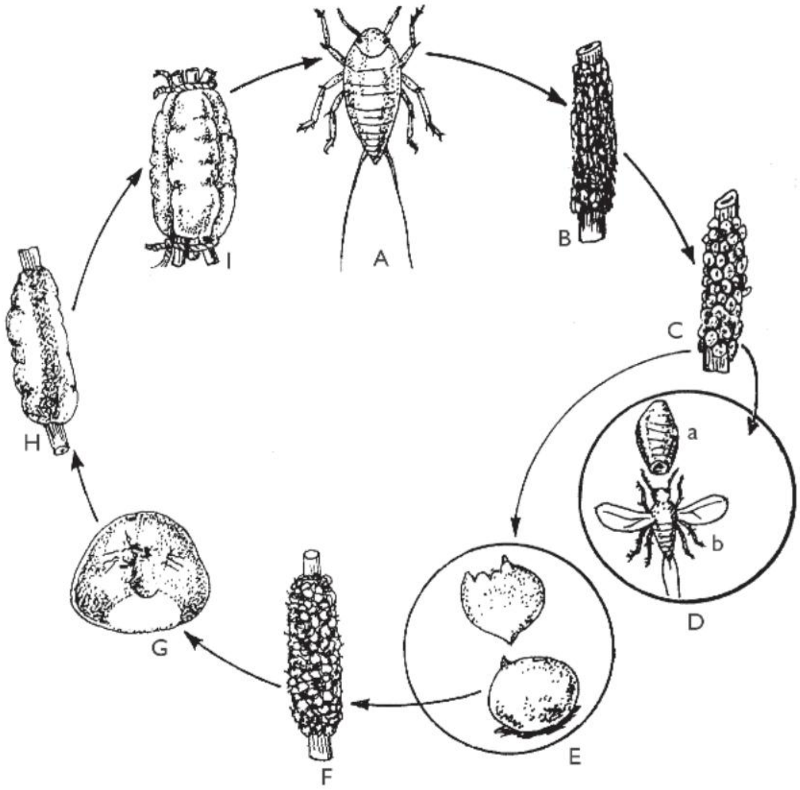
Lac Cultivation

Lac is the resinous secretion of animal origin produced by the tiny homopteran coccid *Kerria lacca*, which spends its entire life period attached to the twigs of several naturally occurring plants. The importance of lac in modern economy is considerable and has entered into the agricultural, commercial, artistic and domestic enterprises in a progressive way. Lac insects have been introduced on a wide variety of host plants and though more than 53 genera and 113 species have been recorded, only seven genera involving 14 species are considered major hosts. These include *Acacia arabica, A. catechu, Butea monosperma, Cajanus cajan, Ficus benghalensis, F. cunia, F. racemosa, F. religiosa, Leea crispa, L. robusta, Schleichera oleosa, Zizyphus mauritiana,* and *Z. xylopyra. Moghamia macrophylla, M. chappar* and *Albizzia lucida* are also known to be good lac hosts. Areas of lac cultivation in India are indicated in Fig. 70.1.



▲ **Fig. 70.1** *Lac cultivation in India.*

The lac insect starts its life history (Fig.70.2) as a tiny, soft-bodied, crimson coloured (though yellow or white forms do occur) nymph emerging in large numbers during certain parts of the year from the lac cells of the females. Each female produces 130–400 nymphs depending on the strain of the insect as well as the cropping season. The nymphs



▲ **Fig. 70.2.** *Life-cycle of the lac insect: A: Crawler B-C: gregarious settling on twigs; D: adults a- Female, b-Male E: lac cells; F-I lac encrustation.*

over the twigs and branches and settle gregariously, the settling rate being 44–103/ sq. cm. For nearly fifteen days, nymphal emergence from a female continues, but from a twig containing many lac females, emergence continues for about three weeks depending on the climate. Their glands commence secreting a day or so after settlement, the nymphs getting encased in cells of their own secretion increasing the size of the insects, which attain maturity after three months. The duration of the instars depends on the host as well as on the climate. Both male and female nymphs lose their legs, antennae and eyes after the first moult, when the sexes could be well differentiated. Males are known to live for 62 – 92 hours after emergence and a male can fertilise as many as 45 females. Winged and wingless males have slipper-like lac cells and they stop feeding after the last instar due to atrophy of the mouthparts. The female nymphs become smaller, pear or sac-like, sexually maturing after the final moult, so that the females become many times larger than the males and are the principal source of secretion. As a result of continuous secretion, lac cells increase in size and continue secretion till egg laying, when the female insect contracts forming a space within. The eggs hatch soon after laying.

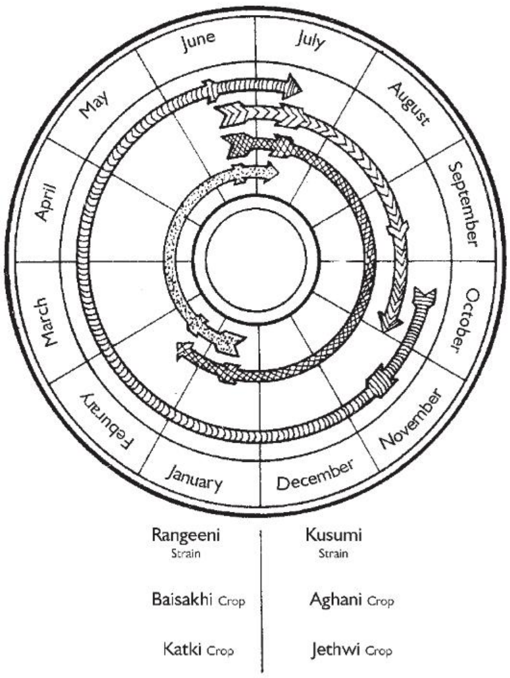
Secreting females carry the resin lac which covers the whole of the body, and as the insects crowd on the twigs, the individual cells coalesce to form a more or less single mass of encrusted lac or stick lac. This is first crushed and screened, opening the cells to wash off lac dye and remains of dead lac. After drying the lac granules and further mechanical cleaning by sieving and winnowing, seed lac is produced and after several mechanical processes shellac is produced. Stick lac has resin, sugar, proteins, soluble salts, colouring matter, wax, volatile oils, woody matter and insect bodies. Two lac strains are recognised in India – the *rangeeni* and *kusumi*, the lac crops raised from them being named after the months in which they emerge. Each strain completes its life cycle twice a year, but the season of maturity differs. In Karnataka, the *rangeeni* strain completes three life cycles in thirteen months on *Shorea talena* occurring in the forests of Karnataka, Southern Deccan and Maharashtra. In other words the lac insect brood is trivoltine, with three annual generations. All others are bivoltine. Since the lac insect entirely depends upon the host plants on which it lives and feeds, successful culture of lac depends upon the proper utilisation of the host plants.

A female may produce 300–1000 larvae so that even from a small patch of encrustation where at least a few hundred females are present, the larvae emerge in thousands and this large scale emergence is often termed the "swarming of larvae". Sticks with lac encrustation containing gravid females are called "brood lac sticks", which are tied together for the purpose of infecting other trees for the successful crop.

The overall production of *rangeeni* lac is six to eight times that of *kusumi*. *Kusumi* lac resin, however, is of superior quality, being mostly grown on *Schleichera oleosa, Acacia catechu, Ficus religiosa, F. racemosa,* etc., while the most common plants for *rangeeni* lac are *Butea monosperma* and *Zizyphus mauritianus*. The age of the host plants when they are mature to take lac production varies from species to species and is mostly 8–10 years. In addition to pure culture on single host plants, mixed culture when alternate hosts are used is also practised, involving *Butea* and *Zizyphus* or *Acacia* for *rangeeni* crops, and *Schleichera* with *Acacia* for *kusumi* crops. *Moghamia macrophylla* has also been found to be good lac yielder of the winter crop, while the summer crop is taken on *Albizia lucida* in alternation under mixed plantation.

Three basic ecological conditions for lac culture appear to be: a) host species deciduous for long periods during the hotter months will not be suitable; b) species should not be tried in areas liable for forest fires; and c) lac does best in open areas where there is plenty of air around the host plant and should not be tried in deep forests.

The main lac crops are *Baisakhi* (April – May), and *Kusumi* (November – December), while the subsidiary crops are *Katki* (October–November) and *Jethwi* (June–July) (Fig. 70.3).



▲ **Fig. 70.3** *Lac crop calendar.*

On an average India has produced 27,000 MT of stick lac per year, of which 53 % is in Bihar, 23 % in Madhya Pradesh, 9 % in West Bengal, and 4 % in Maharashtra. Production of lac varies from 17,000 to 52,000 MT per year, and the average yield of seed lac is about 60 % of stick lac.

◆ Chapter 71

Forensic Entomology

The utilisation of information on insects in certain criminal investigations relating to approximate period when a person is dead as revealed by observation on insects on or in corpses. Anthropologists have made sufficient observations regarding arthropods found on human remains. An interesting aspect relates to the information on blowfly biology on time of death and on whether a corpse has been removed from the place of death to another. As such Forensic Entomology is principally concerned with conclusions drawn from examination of arthropods taken from corpses and utilisation of life history informations under diverse circumstances, to estimate the time of death.

Forensic Entomology dates back to 1855 involving the knowledge of insect fauna of human corpses, such as estimates of mite eggs and life stages of insects such as act of the blow fly *Sarcophaga Carnaria.* A number of landmark publication have been made in the late 18th century, with a noble report in 1898 by M. G. Motter[1] on "A contribution study of the grave".

Forensic Entomology has not developed to the extent that it could be considered as a distinct sub-discipline. In recent years the large scale involvement in idol thefts from various localities including temples, with in many cases their being buried in the soil to escape notice, has often resulted in termite incrustations which when discovered would provide a rough idea as to how long the idols have been hidden.

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[1] M. G. Motter 1898 *J. New York Entomol. Soc.* **6:** 201–231.

◆ Chapter 72

Industrial Entomology

Insects contribute economic products in such magnitude as to surpass any other group of organisms. It is no exaggeration to mention that no other life form in this planet is so inextricably bound up with that of man. Man has made use of insect products such as honey, wax, silk, dyes, medicines and even food, from time immemorial.

Honey is enjoying a renaissance along with natural foods movement and the United States is producing 100,000 MT, not to mention of other countries like China, Argentina and Australia, each of which produce over 10,000 MT. With significant amounts of diverse vitamins and equally diverse minerals, honey has been accepted as a source of essential nutrients. Another insect secretion of equal economic value is beeswax consisting of various fatty acids and hydrocarbons. It has been essentially used for waterproofing, adhesives, insulations, cosmetics and candles, with the churches using around 3 million pounds annually. History also records that they were used in ointments, industrial lubricants, paints and varnish removers, etc.

Sericulture or silk production by the silk moths is a thriving industry from ancient times, with increased inputs every year. Interestingly enough the major silk producer is *Bombyx mori,* preferably feeding on mulberry (*Morus alba)* leaves, consuming 4000 times its own weight from hatching to pupation. It is estimated that 350 cocoons are required to make a pair of silk stockings and around 1700 cocoons for a dress. China leads in world silk production with an annual in put of 30,000 MT of raw silk, which is around 80% of the world supply. Japan closely follows China with around 7,000 MT of raw silk annually. India, Korea, Brazil and Thailand are other world class producers, but comparatively low in out put.

Lac, a waxy secretion of the scale insect, *Kerria lacca,* is the only animal resin of commercial value. It is chemically a complex mixture of various polyhydroxy acids. Most of the world's lac is produced in India, which makes about 88,000 MT a year. Lac is an orange-coloured resinous secretion, which is processed to form the shell-lac of commerce. Lac is used mostly in insulators, varnish, electrical apparatus and sealants. Other uses of lac are varied from jewellery settings to mirror backings. Earlier in the 20th Century it was primarily used in gramaphone record industry.

Another scale insect which produces products of industrial importance is the cochineal insect, *Dactylopius coccus,* the principal dye source, as well in cosmetics, specifically rouge and fingernail polish, besides use in medicine and fabric dyeing. The pigment is carminic acid. This acts as an ant repellent also. For commercial use, the cochineal is scraped off cactus and about 25,000 insects are required to produce around 0.45 kg of cochineal. It is the principal natural source of the scarlet-red dye Carmine, used for staining in laboratories, for dyeing silk and woolen fabrics and colouring confectionary items.

Cantharidin, a well known product of commerce, is produced in nature by the blister beetles or cantharidin beetles. Cantharidin is contained in the acrid oil excreted through the openings at the apex of the legs. The insects yielding this product in India are *Epicauta hirticornis, Lytta tenuicollis, L. actacea, Mylabris cichorii, M. pustulata, M. balteata,* etc. *Mylabris* spp. yield more cantharidin which is used in medicine and as an ingredient in hair oils. The potential of several species of *Chelidonium* for producing drugs effective in liver troubles and for other similar purposes needs to be exploited.

Plant galls which are abnormal plant growths are very rich in tannic acid, a mixture of compounds including gallic and ellagic acids. Some Oak gall nuts have 50-70% tannic acid, very much in demand for dyeing leather and used extremely by the leather industry. Tanning is a process where proteins of animal hides are complexed and tannic acid is an excellent binder of proteins and prevents rotting of hides.

Insects have been in use in medicines in several countries, and the therapeutic value of bee venom is becoming more widely recognised and there are a number of commercial preparations available today. It is particularly used in the treatment of rheumatism.

In view of diverse patterns presented by several insects like the beetles, they are used by artists, jewellers and designers for their aesthetic value. Bracelets, necklaces, neck tie pins, etc. are very often made with insect designs. Fascinating butterflies as well as large moths like the moon moth and Atlas moth (Fig. 72.1) are mounted in small glass cases as decorative items and have very good market value. Equally valuable are insect depicted paintings very significant of Japanese art.

Insects are being eaten in many parts of the world from ancient times to the present day. Consumption of insects in S. E. Asia is widespread with large scale business in the sale of belostomatids, the water bugs, and also its spicy juice called *namphala*. In Mexico eggs of water bugs are sold in the markets. A plate of crickets is considered as a compliment in Jamaica. Natives of Australia roast the moths of *Agrotis infusa* in oil, which taste like nuts and almonds. In Uganda long-horned grasshoppers known as "Nasenene" are eaten either raw or cooked. Further, the mounds of the large termite, *Macrotermes bellicosus,* around Lake Victoria in Uganda are regarded as the property of different families and the women and children collect them while swarming and eat them after roasting. In some African countries such as Botswana, Zaire, Zimbabwe and South Africa caterpillars of *Gonimbrasia belina,* known locally as *mopaine,* are sold which forms a good protein source in the place of beef. A similar preference has been reported among Yupka tribes of Colombia and Venezuela. In Mexico grilled queen ants and canned silkworm larvae form delicacies in restaurants. Further, the larvae of the giant skipper *Aegiale hesperiaris* is considered a delicacy under the name "Gusanos de Maguey" which are sold fresh in the market and fried before eating. In Nigeria termites, crickets, palm weevils and rhinoceros beetles are eaten. In Singapore termite queens are sold in markets, which are eaten alive, dipped in alcohol or preserved in rice wine. In Saudi Arabia locusts grilled, boiled or fried are considered delicious.

▲ **Fig. 72.1** *Butterflies and moths in show cases for sale in Bangkok (Courtesy: B. V. David)*

In India termites as well as grubs of honey bees are eaten by some tribes particularly in Karnataka. In Karnataka roasted termites that look like brownish popped rice are sold in the market. In Assam, Tasar and Muga silkworm pupae are eaten after stifling and reeling the silk from the cocoons. In Andhra Pradesh and Karnataka pupae of the mulberry silkworm after stifling are eaten. The dead pupae of Eri silkworm are either consumed by local tribes, or are dried and powdered and used as feed for poultry, pigs or fish.

Dungsee, a sweet product prepared from the honey dew excreted by the giant willow aphid, *Tuberolachnus salignus,* to the extent of 2–5 kg/tree depending on severity of infestation, is a rich source of carbohydrate (67.98% total sugars), protein (10.15%) and minerals (1.6%). In Spiti Valley and its adjoining areas in H.P., the tribals are known to relish this sugary substance *Dungsee.*

Other products from mulberry silk worms include the gut used in surgery, fatty matter of chrysalids for soap manufacture and the protein-rich chrysalids used as a fertilizer. The sericultural wastes such as silkworm litter, left over mulberry leaves, etc. are composted or even used for preparation of vermin compost.

Each 100 g of roasted crickets and termites appear to provide 617 calories of energy. The protein content of 100 g caterpillars is 28 g and of termites 14 g. The vitamin and micronutrient content of these insects are several folds higher. Further, insects are low in cholesterol content.

With emphasis on Integrated Pest Management the use of insects, pathogens and viruses in biological control of major pest species has assumed greater importance. A number of commercial insectaries and companies produce biocontrol agents and biopesticides and supply to the farmers.

INTRODUCTION

In thier attempts to secure food, insects inflict considerable damage to almost every part of plants and the seriousness of the attack may be decided not only by the nature of the injuries inflicted, but also by the susceptibility of the plants concerned to insect attack. The two main types of insect feeding, the biting and the sucking types, are well known and the effects of feeding may be direct, causing outright injuries or indirect through helping in the transmission of diseases—bacterial, fungal or viral.

Biting insects by feeding on the growing points of plants cause retardation of growth and often cause defoliation by feeding on leaves. They may notch the edges of leaves or make holes by feeding or roll up the leaves and feed from inside or only feed on a layer of surface tissue. Sometimes they may live concealed under loose bark of plants or cut the tender stems of plants at the time of germination. By feeding on the flower buds and flowers of plants, a reduction in seed production is often caused. In addition to feeding partially on the grains of cereal crops, they may nibble and cut off entire ear heads.

Insects with sucking habits cause a general chlorosis of leaves or a silver whitening of the leaf surface, or yellow specking or brownish necrotic lesions. Crinkling and curling of leaves is a common effect. Infestation in large numbers on the shoot and fruits often cause a premature shedding of developing fruits or piercing of the rind of fruits and sucking their juice cause premature fruit fall.

Injuries are also caused by internal feeders, feeding from within the plant tissues, some called the borers, boring the internal tissues and others called the miners, mining the leaf tissue. Many plant tissues react to insect salivary toxins during feeding, by the formation of galls or abnormal outgrowths and due to this toxaemia the growth of plants may be impaired and the setting of fruits, seed and grain adversely affected.

Another aspect of injury is through feeding by subterranean insects living in the soil, feeding on the roots of plants by chewing, or boring, sucking, or by formation of galls. In general, the attack result in stunting, discolouration, withering and death of the plants. The serious damages caused by insects to stored products are well known.

The indirect effects of feeding are evident in the loss of quality of produce through reduction in the nutritive value or marketability. Through mechanical or biological transmission of disease agents, such as bacteria, fungi and viruses, insects are indirectly responsible for the severe damage and loss caused. Injuries are also caused by oviposition.

As has been discussed under population dynamics, the equilibrium or stability of insect populations may be upset resulting in very favourable opportunities for abnormal increase of populations of species making them reach pest proportions. They reach a pest status when they are responsible for 5 % of the loss of yield and are designated minor and major pests when the loss ranges from 5 to 10 % and more respectively. According to the periodicity of their occurrence insect pests are said to be regular, occasional, seasonal, persistent or sporadic and sometimes, severe infestations often result in an epidemic. The major causes for the outbreak of insect pests is the destruction of forests or bringing them under cultivation, destruction of the natural enemies, predators and parasites, intensive cultivation of crops, introduction of new crops and new strains, accidental introduction of foreign pests, resurgence of pests, etc., to mention a few.

Prior to the adoption of control methods for insect pests, assessment of populations as well as estimation of the damage caused are important. Population assessment is usually done by actual counting as in bigger species, but mostly sampling methods are adopted. Varied sampling methods are used for different insects. These are not only according to the niches they occupy, but also on the basis of the nature of the crop attacked and distribution of the species of the pests. It may be indicated that such methods as net sweepings, sudden trappings, light, water, suction and sticky traps, are some of the common methods adopted for the control of insects.

As to the estimation of damage caused by insect pests to crops, both qualitative and quantitative methods are employed. These include conducting widespread surveys all over the country for several years or from experimental plots by comparing two plots, one subjected to natural infestation and the other maintained under controlled conditions, the degree of infestation and ultimate yield or correlation of yield per unit area in different fields with the degree of infestation of a particular pest in such areas.

The pests of crops in the field and storage, pests of forest trees and nurseries, pests of medical and veterinary importance, household pests and insect vectors of plant diseases are important categories of harmful insects. Most of them have been elaborated in detail under Part II–Taxonomy and Pestology. However, in this section the pests of importance in storage, forest, human and animal health and household are outlined briefly.

Section Eight

Harmful Insects

◆ Chapter 73

Storage Entomology

Excess moisture and mould, insects and rodents are known to be responsible for damage and loss to stored products. Excess moisture and mould are mainly responsible for the deterioration in quality of stored materials. Insects and rodents feed on the stored products and thus account for serious damage and loss. The important insect species responsible for loss in stored products are detailed hereunder.

INTERNAL FEEDERS

The larvae feed entirely within the kernels or grain or stored material.

1. THE RICE WEEVIL *Sitophilus oryzae* Linn. (Curculionidae : Coleoptera)

The weevil measuring 4 mm long is dark brown and has four light reddish or yellowish spots on elytra. The female makes a small hole on the grain, deposits an egg and covers it with a gelationus fluid. In a period of four to five months a female may lay from 300 to 400 eggs. The apodous grub feeds inside the grain, pupates there itself and emerges through an irregular hole made on the grain. The life cycle ranges from 26-28 days.

The insect infests the grain both in storage and in field. It is destructive to wheat, corn, rice, *cholam* (*Jowar*), etc.

2. THE SWEET POTATO WEEVIL *Cylas formicarius* Fb. (Apionidae)

This is a pest of importance of sweet potato in storage and in the field. See under Order Coleoptera.

3. THE LESSER GRAIN BORER OR PADDY BORER BEETLE *Rhyzopertha dominica* Fabr. (Bostrychidae : Coleoptera)

The dark brown beetle measuring about 4 mm in length has its head bent under the thorax and the posterior abdominal end blunt. Antenna is serrated and three segmented. The grubs develop within kernels or may feed in wood and paper. It is particularly a pest of unhusked paddy becoming serious occasionally. It also attacks wheat. It also infests milled products such as flour, *atta*, etc. It completes its life cycle in about 25 days.

4. THE CIGARATTE OR TOBACCO BEETLE *Lasioderma serricorne* Fb. (Anobiidae : Coleoptera)

This light brown round beetle has its thorax and head bent downward and this presents a strongly humped appearance to the insect. The elytra have minute hairs on them. Antenna is of uniform thickness. The whitish hairy grubs feed on stored tobacco, ginger, turmeric and chillies. The creamy white oval eggs are laid on the surface of stored material and the incubation period is 9–14 days. The larval and pupal periods range respectively from 17–29 days and two to eight days. Redrying of tobacco; fumigation with aluminium phosphide tablets (20–30 tablets for 28 cu. m. for 96 hrs) and aeration of tobacco for 72 hrs; storing at 16–18°C; fogging with DDVP aerosol @ 1 to 2 g a.i./28 cu. m. once or twice a week; or fumigation with magnesium phosphide 56% plate at 4 plates/25 tonnes tobacco stack and an aeration period of 48 hrs are recommended as control measures.

5. THE DRUG STORE BEETLE *Stegobium paniceum* (Linn.) (Anobiidae : Coleoptera)

This reddish brown small beetle has striated elytra and measures 3 mm long. Antenna is clubbed. It lays the eggs in batches of 10 to 40. Grub is not hairy but is pale white, fleshy with the abdomen terminating in two dark horny points. It tunnels into stored products like turmeric, ginger, coriander and dry vegetable and animal matter. The larval and pupal periods occupy respectively 10 to 20 months and 8-12 days.

6. THE PULSE BEETLE *Callosobruchus maculatus* (Bruchidae : Coleoptera)

The pulse beetle is small, dark brown and abruptly rounded at the posterior end. Adult beetle lays 80–100 white, elongate eggs singly glued to the surface of the pod in the field or on grains in storage. The grubs feed on the inner contents of pulses and pupate inside them. The egg, larval and pupal periods are respectively 5, 30–50 and 4–14 days. It causes appreciable damage to stored cowpea (Fig.73.1), grams, *Lab-lab niger*, etc. It also infests redgram pods in the field.

▲ **Fig. 73.1** *Cowpea seeds damaged by Callosobruchus maculatus*

7. THE TAMARIND BEETLE *Caryedon serratus* Oliv (Fb.) (Bruchidae : Coleoptera)

The grubs of the grey beetle attack the seeds of tamarind in storage as well as on trees.

8. THE ANGOUMOIS GRAIN MOTH *Sitotroga cerealella* Oliv. (Gelechiidae : Lepidoptera)

The yellowish white moth has pale fore wings and uniformly grey pointed hind wings with fringes of hairs. The female lays about 100 eggs on the surface of grains. The caterpillars feed on the internal contents of grains and pupate inside the grains. It may hibernate in winter in pupal stage. It inflicts severe damage to unhusked paddy. It attacks ripening grains of paddy, *cholam* and *ragi* in the standing crop and the grains in storage.

9. THE POTATO TUBER MOTH Phthorimaea operculella Zeil. (Gelechiidae : Lepidoptera)

It is a serious pest of tubers in storage and in the field. For details see under Order Lepidoptera.

10. THE CIGAR BEETLE *Demobrotis* sp.

The stored cigar-wrapper tobacco is attacked by this pest.

EXTERNAL FEEDERS

The larvae and adults feed on the grains from outside.

1. THE RED FLOUR BEETLE *Tribolium castaneum* (Herbst) (Tenebrionidae : Coleoptera)

The beetle is small, reddish brown and flat. It attacks grains, seeds, vegetable powders, dry fruits, oil cakes, nuts, museum specimens like dry insects and stuffed material, etc. The white translucent, sticky, slender and cylindrical eggs are laid at random in the produce and a female lays up to 450 eggs over a period of many months. The transition from egg to adult takes three to four weeks.

2. THE INDIAN MEAL MOTH Plodia interpunctella Hubner (Phycitinae : Lepidoptera)

This moth has brown forewings with white band. It lays about 300 eggs in clusters and the life cycle is completed in about five to six weeks. It is a pest of ear and grain of maize and ear and grain of maize and also cereals, groundnut and dried fruits. The insect contaminates grains with excrement, cast skins, webbings, dead larvae and pupae. The larva first feeds on the embryo of the grain and while feeding spins a silken web on which the larval droppings and particles of broken grain get attached.

3. THE FIG MOTH Cadra cautella W. (Phycitidae: Lepidoptera)

This small moth has dirty white to greyish wings with indistinct black bands. At rest the wings are sloped over the body almost like the slanting roof of warehouses. The larva mainly feeds on the germ portion leaving the rest of the kernel undamaged. It also attacks dried fruits. In bulk food grains its damage is limited to peripheral top layers only. Web formation by the insect covers the bags, floor space and mill machinery thereby leading to clogging in mills. The eggs are laid in the produce, often by simply dropping them, through the holes between fibres of jute bags, or freely on the surface of the produce. A female lays about 300 eggs. The egg, larval and pupal periods are respectively, three to six days, four to six weeks and one to two weeks.

4. THE RICE MOTH Corcyra cephalonica Staint. (Galleriidae: Lepidoptera)

The adult moth is greyish brown. The caterpillars web together the grains and feed within. It attacks broken grains. The grains should be cleaned and dried well in the sun.

Stored grains pest management

Preventive measures

a. Disinfest the store houses with malathion 50% EC or pirimiphos-methyl 50% EC in the ratio of 1:100 applied at 3 litres / m^2.

b. The store houses should be clean and all the swept material such as dust, dirt, rubbish, webbing, etc, should be burnt or buried deep in the soil.

c. Cracks and crevices in the wall, floor, and ceiling should be plastered.

d. Clean the grain and remove all foreign material and broken grains.

e. Excess moisture in the grain causes heating and development of mould, which give rise to disagreeable odour, discolouration and even caking, if neglected.

The bags or bins can be made damp proof by providing dunnage of bamboo poles or bamboo matting or wooden crates.

Curative measures

a. Ecological control measures: Temperature, moisture and availability of oxygen are factors needed for the development of insects. Hence, they have to be suitably manipulated through design and construction of storage structures, and storage practices so as to create ecological conditions unfavourable for the development/attack of insects. Immature stages of *Sitophilus oryzae, Rhyzopertha dominica* and *Sitotroga cerealella* get killed when exposed to temperature 80, 70 and 60°C for about 4, 6 and 11 minutes, respectively. Similarly grain stored around 10% moisture content escape from the attack of insects (except Khapra beetle). The oxygen limit inside the grain containers lethal to different insects and their stages ranged from 0.21% to 12.84%. This can be achieved by purging with nitrogen or addition of carbon dioxide.

b. Physical control measures: Use of gamma rays at doses of about 500,000 rads produce sterilisation, death within 24 hours and provides high control of microflora, while doses of about 100,000 rads produce sterilisation death in about a week and minimise damage caused by feeding.

c. Cultural control measures: Pulse beetles prefer to attack wholesome seeds and not split ones. Split pulses being dry, escape from the attack and as such are most suitable for storage than wholesome pulses. Treatment of pulses with coconut/groundnut/mustard oil at 0.25 to 0.50% can protect the pulse from the attack of pulse beetle up to 6 months.

d. Chemical control measures

(i) Fumigation of grains: The stocks of grains should be periodically examined and if insects are noticed the stock should be removed, sun-dried and cleaned. Heavily infested material should be fumigated. Fumigate the grains under cover or inside a shed with aluminium phosphide tablets (each tablet weighs 3 g) at 6 g/tonne or 1.5 g/m^3, the exposure period being six to seven days. Magnesium phosphide is also used in the form of tablets/plates. After fumigation aeration is necessary for 72 hours. Fumigation is allowed only under the supervision of trained personnel.

(ii) Surface spray of bags (prophylactic treatment): The bags should be stacked in such a way as to allow proper ventilation and sufficient moving space for periodical inspection. Malathion at 15 ml of 50% EC/4.5 litres of water may be sprayed, as a thin film on bags and about 3 litres of the spray solution may be necessary for 100 sq. m. If drenched, the humidity of grain may increase and infestation may take place. Other insecticides suggested are pirimiphos methyl 50% EC at 10 ml/litre water applied at 3 litres/100 m^2 or deltamethrin 2.5% WP at 0.5 g or cypermethrin 25% EC or fenvalerate 20%EC at 6 ml in 3 litres water/100 m^2.

The incoming new stocks of grain should not be stored along with old or infested stocks in the godown.

◆ Chapter 74

Forest Entomology

Forests constitute an area of 56 million hectares in India. Insects play a major role in the destruction of Indian forests insects due to their high reproductive potential and presence of many generations in a single year. The annual loss caused by insects to seeds, transplants, standing trees, wood and finished product has been computed to be about 10 % of the total revenue from the forests. Forest entomology constitutes study of the insect pests of forests, forest products, nurseries and seeds. It may be illustrated as below.

Forest Entomology

- Pests of nurseries
- Pests of standing trees :
  - i. Pests of natural forests
  - ii. Pests of man-made industrial plantations
- Pests of seeds and fruits
- Pests of felled and stored timber
- Pests of forest products

I. PESTS OF NURSERIES

Forest nurseries are the motherland of forestry programme; as often non-availability of large number of seedlings required for raising forests becomes a major constraint due to damage to nursery plants by insects apart from nematodes, diseases, etc. The following list indicates insects affecting forest nursery plants in India.

Insect Pest	*Host*	*Nature of Damage*
Chafers/White grubs		
Holotrichia consonguinea (Coleoptera: Scarabaeidae)	*Acacia nilotica* *Albizia lebbek* *Prosopis cineraria*	Grubs feed on rootlets and cortical tissues of seedlings
Maladera insanabilis Brenske (Coleoptera: Scarabaeidae)	*Prosopis cineraria* *Acacia nilotica*	Adults feed on leaves
Rhinyptia laeviceps Arrow (Coleoptere: Scarabaeidae)	*Prosopis cineraria* *Acacia nilotica*	Adults feed on leaves
Schizonychus ruficollis F. (Coleoptera: Scarabaeidae)	*Acacia nilotica* *Tecomella undulata*	Adults feed on leaves
Root feeders		
Odontotermes obesus (Isoptera: Termitidae)	*Acacia nilotica* *Dalbergia sissoo*	Workers feed on underground roots and stem
Microtermes mycophagus (Desneux) (Isoptera: Termitidae)	*Acacia nilotica* *Dalbergia sissoo*	Workers feed on underground roots and stem
Defoliators		
Brachytrypes portentosus Litch. (Orthoptera: Gryllidae)	*Tecomella undulata* *Albizia lebbek*	Nymphs and adults cause damage by cutting young seedlings
Papilio demoleus Linn. (Lepidoptera: Papilionidae)	*Albizia lebbek*	Larvae feed on leaves
Plecoptera reflexa Guenee (Lepidoptera: Noctuidae)	*Dalbergia sissoo*	Larvae feed on leaves
Myllocerus dalbergiae Ramamurthy (Coleoptera: Curculionidae)	*Moringa oleifera* *Dalbergia sissoo*	Adults feed on leaves
Patialus tecomella Pajani (Coleoptera: Curculionidae)	*Tecomella undulata*	Grubs feed on leaves
Myllocerus curvicornis	*Acacia nilotica, Pongamia glabra, Tamarindus indica*	Feed on leaves
Myllocerus tenuicornis & M. viridanus (Coleoptera: Curculionidae)	*Acacia nilotica, Tamarindus indica*	Feed on leaves
Sap suckers		
Aphis gossypii Glov. (Hemiptera: Aphididae)	*Albizia lebbek*	Sucks from tender shoots
Acaudaleyrodes rachipora (Singh) (Hemiptera: Aleyrodidae)	*Acacia nilotica* *Acacia tortilis* *Acacia senegal* *Albizia lebbek* *Cassia fistula*	Infests tender leaves

(Contd.)

Insect Pest	*Host*	*Nature of Damage*
	Dalbergia sissoo *Delonix regia* *Eucalyptus* ssp. *Leucaena leucocephala* *Moringa oleifera* *Parkinsonia aculeata* *Pongamia pinnata* *Prosopis cineraria* *P. juliflora* *Tecomella undulata*	
Helopeltis antonii (Hemiptera : Miridae)	*Azadirachta indica*	Infests tender shoots
Psylla hyalina (Hemiptera : Psyllidae)	*Albizia lebbek*	Tender shoots
Pulvinaria maxima (Hemiptera: Coccidae)	*Azadirachta indica*	Infests tender shoots
Oxyrachis tarandus Fabricius (Hemiptera: Membracidae)	*Acacia nilotica* *Albizia lebbek* *Prosopis cineraria*	Infests tender shoots
Dysdercus cingulatus Fb. (Hemiptera: Pyrrhocoridae)	*Pongamia pinnata*	Infests tender shoots
Eurybrachis tomentosa (Fb.) (Hemiptera: Eurybrachidae)	*Acacia nilotica* *Albizia lebbek* *Dalbergia sissoo* *Prosopis cineraria* *P. juliflora*	Infests tender shoots

II. PESTS OF STANDING TREES

A. Pests of natural forests

1. CHIR *(Pinus roxburghii)*

The important pests of chir are the bark borer *Cyrtorrhynchus rufescens,* and the bark beetles *Ips longifolia, Pityogenes scitus* and *Polygraphus major. C. rufescens* attacks living chir saplings. The weevil grub bores the bark and causes formation of cankerous wounds resulting in death of the tree. *Ips longifolia* (Scolytidae) bores into the bark of large tree trunks and small branches. The attack results in characteristic polygamous gallery pattern in attacked tree trunks. *P. scitus* (Scolytidae) attacks the thin green bark or rind of living branchlets and stems of young and old trees. *P. major* also attacks small branches and stems and causes polygamous gallery system.

2. DEODAR *(Cedrus deodara)*

The scolytid beetles *Ips longifolia, Pityogenes scitus* and *Polygraphus major* also attack deodar. The cicadid, *Paharia casyapae,* oviopsits in the branchlets and stems. *Ectropis deodarae* (Geometridae) defoliates the pure deodar forests of the outer ranges of the Himalayas and in Punjab. Recently about 100,000 deodar trees in Himachal Pradesh were affected by this defoliator. *Dioryctria abietella* and *Euzophera cedrella* (Pyraustidae) bore into the cones.

3. OAK *(Quercus sp.)*

The larvae of *Dorysthenes hugelli* (Cerambycidae) bore into roots of oak trees. The larvae of another cerambycid, *Aphrodisium hardwickianum,* bore into the stems of living trees.

4. SAL *(Shorea robusta)*

The sal heartwood borer, *Hoplocerambyx spinicornis* attacks felled trees, damaged trees or infected by root fungus. This is considered to be the most injurious forest insect in India. During 1997-98 it became an endemic pest of sal in M.P. and affected one sixth of the total sal forests spread in six districts covering an area of 300,000 ha inflicting a loss of Rs.2500 million. The insect attack is believed to have started in December 1995. The sal tree produces resin that attracts the insect. With the onset of the monsoon, the adult beetles emerge and mate. The female lays, on an average, 250 eggs in the bark of the tree. The incubation period is seven days. The grubs remain active for six to seven months (June to November), gnawing into the whitish sapwood and the red-brown heartwood. The grubs form galleries, eating their way in and out, and up and down the stem of the tree. It pupates within the stem and emerges when the monsoon sets in the next season. The longevity of adults is three to four weeks. The adults are strongly attracted to fresh sap of felled trees and are known to fly up to 0.8 km within five minutes and are capable of smelling the sap from a distance of 2 km. The insect was first noticed as a pest of sal in 1899 and since then several epidemics have been recorded in states like Assam, Bihar, H.P., U.P. and M.P. During 1923-28 epidemics 4,28,000 adult beetles were killed. During 1997 in M.P. about 15,100,000 adult beetles were collected and killed.

Pammene theristis (Eucosmidae) attacks the seeds, seedlings and young shoots. The lymantriid *Lymantria mathura* is a principal defoliator of Sal in Assam and North India.

5. SPRUCE *(Picea smithiana)*

The spruce budworm *Eucosma hypsidryas* Meyrick (Eucosmidae) oviposits on young buds of spruce. In each bud a single larva feeds on the undeveloped needles inside without damaging the needles that form the outer most and lowest layer. The damaged bud becomes brown and dries. This prevents normal annual formation of new shoots and results in extensive loss of radial growth. The larva of the pyralid *Dioryctria abietella* also bores the cones.

B. Pests of man-made industrial plantations

1. BAMBOO *(Bambusa spp.)*

The beetle *Estigmena chinensis* (Chrysomelidae) is a serious pest of bamboo forests in India. It attacks young clumps. *Cytrotrachelus dux* (Curiculionidae) is a borer of young sprouting culmns of bamboos. The larvae of *Cosmopteryx bambusae* mine the leaves of bamboo.

2. BABUL *(Acacia arabica)*

A dirty brown scale *Anomalococcus indicus* infests the branches and stem. The hairy caterpillars *Taragama siva, Metanastria hyrtaca* and *Euproctis lunata* also damage the leaves. The metallic coppery green buprestid beetle *Psiloptera cupreosplendens* gnaws the bark of thin shoots.

3. CASHEW ***(Anacardium occidentale)***

The cashew tree borer *Plocaederus ferrugineus* (Cerambycidae) is an important pest of cashew. For more details refer to the section on Coleoptera. The leaf miner *Acrocercops syngramma* (Gracillariidae) is yet another pest of common occurrence. For more details refer to the section on order Lepidoptera.

Other insects include the shoot and blossom webber *Lomida moncusalis* Walk. and the shoot tip and inflorescence caterpillar *Chelaria haligramma* M. These are often serious pests on cashew. The thrips *Selenothrips rubrocinctus* G. and *Rhipiphorothrips cruentatus* Hood damage the leaves. The caterpillar and thrips pests are easily controlled by spray application of profenofos 0.05 %.

THE CASHEW LEAF FOLDER ***Syllepta aurantiacalis* Fisch. (Pyralidae)**

This species is reported from Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Orissa, Maharashtra and Goa as attacking cashew. Its other host includes cotton. It assumes importance during flushing (September- December) and the larvae fold the leaves causing ultimate drying of leaves by its feeding. The moths are dull yellow with brown wavy markings on both the pairs of wings. Females mate a day after emergence and lay eggs two days after mating. A female lays 60-100 eggs singly or in groups on either side of leaves and the incubation period is three to five days. The larva feeds by scraping the leaf tissue remaining inside the leaf fold and when full grown in 22–28 days measures 25–30 mm long. It pupates inside the leaf fold and the adult emerges in six to eight days. Spraying monocrotophos 0.05%, chlorpyrifos 0.05% or endosulfan 0.05% is suggested.

The bark borer *Indarbela tetraonis* (Metarbelidae), the leaf caterpillar *Cricula trifenestra* H. (Saturniidae), the hairy carterpillar *Metanastna hyrtaca* C. (Lasiocampidae), the looper *Oenospila flavifuscata* W. (Geometridae), the tea mosquito bug *Helopeltis antonii* S. (Miridae), the slug caterpillar *Latoia lepida*, the aphid *Toxoptera odinae* and the apple borer *Nephopteryx* sp. *Apion tumidum* D. (Apionidae : Coleoptera) is found as a pest of cashew in Orissa during March-October. The tiny black adults nibble at the growing apical shoots.

4. CASUARINA

The needle of *Casuarina equisetifolia* is bored by the larva of *Eurnenodera tetrachorda* (Cosmopterygidae) leaving the epidermis intact. The other insects attacking casuarina are: *Zeuzera coffeae*, *Indarbela quadrinotata*, the bag worm *Eumeta crameri* (Psychidae) and the coccid *Naiacoccus serpentinus*. The sapling borer *Sahyadrassus malabaricus* is of minor importance.

5. TEAK *(Tectona grandis)*

Teak is considered to be one of the most valuable timber trees of India. Among the insects that attack teak plantations in South India the two species of defoliators are considered as the most important.

(i) THE TEAK DEFOLIATOR, *Hyblaea puera* Cramer (Hyblaeidae: Lepidoptera)

It is primarily a defoliator of teak occurring abundantly during April-June and occasionally during August-September in South India. The larvae feed entirely on tender leaves and skeletonise the older leaves. There are 12-14 generations in a year. It is reported to be responsible for 44 per cent loss of potential volume growth of the tree.

(ii) THE TEAK SKELETONIZER *Eutectona machaeralis* Walker (Pyralidae: Lepidoptera)

In South India it is abundant in April - May and November. It also feeds on *Callicarpa arborea, C. macrophylla* and *Tectona hamiltoniana*. The larva skeletonises the leaf uniformly. The moth has bright yellow fore wings with pink zigzag transverse markings. The pattern and colour of markings vary depending on season. The moth lays 250–500 eggs singly on leaves and the incubation period is two to threee days. The grown up larva is green with brown or yellow longitudinal bands laterally and measures 22–25 mm long. The larva becomes full-grown in 18–27 days and pupates on the leaf itself or on fallen leaves. The pupal period is 4–11 days. In South India no hibernation occurs in the insect. There are

10-12 generations in a year. As this pest feeds on older leaves towards the end of the growth season no significant impact on tree growth is discernible.

(iii) TEAK BORER *Alcterogystia cadambae* (Moore) (Lepidoptera: Cossidae)

It is an important pest of standing teak trees in Kerala, Tamil Nadu and Karnataka states. It causes extensive bark injury, riddling the bark with numerous holes. The infested tree subsequently gets infected by fungi resulting in the death as well as decay of wood. Usually trees above 15 years old are attacked. Initially the caterpillar feeds on bark and sapwood in the axis of side shoot and then tunnel into the heartwood. The larval stage lasts for about eight months and the larvae pupate in the soil. Presence of bore holes will seriously affect the commercial value of converted teak.

The other species of teak defoliators in South India are *Acherontia lachesis* F., *Psilogramma menepheron* C. (Sphingidae), *Ascotis infixaria* W., *Boarmia fuliginae* Hmpsn., *Cleora alienaxia* W., *Ectropis bhurmitra* W., *Hyposidra successaria* W., *H. talaca* W., *Orsono baclelia* C. (Geometridae), *Dasychira grotei* M., *Olene mendosa* Hubn; (Lymantriidae), *Spilarctia obliqua* B. (Arctiidae) and *Spodoptera litura* (F.) (Noctuidae). The larva of *Labdia callistrepta* Meyr. (Cosmopterygidae) produces brown blisters on upper surface of leaf due to mining under the epidermis. Larva of *Syllepte straminea* B. (Pyralidae) rolls the leaf. The leaf beetles include (*Colasposoma downsei* Baly, *Nodostoma bhamoense* Jacoby (Eumolpidae), *Astycus aurovitatus* H. and *Cyphicerinus tectonae* Mshll. (Curculionidae). *Aularches miliaris* L. and *Teratodes monticollis* Gray (Acrididae) sometimes feed on leaves. The grub of a black or dull brown weevil *Alcidodes ludificator* Faust (Curculionidae) bores through the shoot of teak saplings and kills it. The larvae of *Indarbela quadrinotata* W. and *I. tetraonis* M. (Metarbelidae) are the bark borers on teak. Another borer of teak sapling is *Sahyadrussus malabaricus* (Moore) (Hepialidae). Sap feeding insects noticed on teak are *Otinotus oneratus* W. (Membracidae), *Ptyelus nebulosus* F. (Cercopidae), *Tettigoniella ferruginea* F. (Cicadellidae), the aphid *Aphis gossypii* G. (Aphididae) and the mealy bug *Maconellicoccus hirusutus* G. The inflorescence is damaged by *Leptocentrus vicarius* W. (Membracidae) and the pods and seeds by *Conogethes punciferalis* G. (Pyralidae). The sap wood borers of teak are *Clytus minutus* Gardner and *Xylotrechus quadripes* Cher. (Cerambycidae). The shot hole borers are *Xleyborus andrewsi* B, *X. butamali* B., *X. noxius* S., *X. semigranosus* B. and *X. testaceus* W. (Scolytidae). Teak branches are attacked by the jewel beetle *Psiloptera fastuosa* F. (Buprestidae).

6. SANDAL WOOD TREE (*Santalum album*)

The young saplings are bored by larvae of *Zeuzera coffeae* (Zeuzeridae). The leaves are webbed together by larvae of *Cacoecia micacaeana* (Tortricidae). The foliage is damaged by *Letana inflata* (Tettigoniidae) and is a vector of spike disease of sandalwood. A leafhopper

Jassus indicus (Cicadellidae) attacks tender shoots. The tender leaves are formed into galls due to attack by two species of thrips *Crotonothrips davidi* and *Mesothrips manii.*

7. MAHARUK *(Ailanthus triphysa)*

Among the insects that attack this softwood species the lepidopterous defoliators *Atteva fabriciella* S. (Yponomeutidae) and *Eligma narcissus* C. (Noctuidae) are important. Defoliation by *A. fabriciella* on one to two year old plants causes death of the plants and older plants get weakened. The larvae even feed on inflorescence and seeds. Its life cycle occupies 22-33 days. *E. narcissus* is abundant during September - February.

8. Eucalyptus

The termites *Odontotermes* sp. and *Microtermes* sp. cause more than 90 % damage. The taproot is ring-barked resulting in death of the affected plant. Drenching the plant with chlorpyrifos 20 EC 50 ml/5 litres of water is recommended. The adults of the beetle *Celosterna scabrator* (Lamiidae) feed on tender shoots and bark up to sapwood and thus kill the shoots or break them outright. The larva bores the stem as well as roots and cause yellowing and wilting. The beetle attacks *Eucalyptus citriodora, E. grandis* and *E. tereticornis.* Adults of *Batocera rufomaculata* (Cerambycidae) have been found to girdle the shoots and cause drying of them. The sapling borer *Sahyadrassus malabaricus* is of minor importance.

9. NEEM (*Azadirachta indica*)

A very common pest on neem trees is the mealy scale, *Pulvinaria maxima.* The tea mosquito bug *Helopeltis antonii* S. infests tender shoots. The thrips, *Megalurothrips chaetogastra* Ramk. infests flowers and leaves and *Dolichothrips indicus* (Hood) the leaves. The seeds are bored by the anthribid beetle *Araecerus fasciculatus* DeGeer.

10. Millingtonia *(Millingtonia hortensis)*

The leaves are damaged by *Acherontia styx* and *Hyblaea puera.*

11. MAHOGANY *(Swietenia macrophylla)*

The shoot borer *Hysipyla robusta* is the major pest and attacks saplings resulting in the death of leading shoot. This has affected the establishment of plantations.

12. ALBIZIA (*Paraserianthes falcataria)*

The bagworm *Pteroma plagiophleps* when infests heavily can lead to growth retardation, die-back and even death of trees. However, it is a sporadic pest. The bark feeder *Indarbela quadrinotata* and the yellow butterfly *Eurema blanda* also attack this tree.

13. SUBABUL (*Lucaena leucocephala*)

The psyllid *Heteropsylla cubana* (Crawford) (Psyllidae). The tree is under serious threat from this exotic psyllid, which sucks its sap damaging young shoots and even suppressing growth of the trees. In Kerala the dragonfly *Pantala flavescens* (Fb.) is predaceous on the psyllid. The other predators recorded in India are: *Irantha armipes* Stal., *Sphedanolestes attrimus* Distant (Reduviidae), *Coccinella transversalis* Fab., *Cheilomenes sexmaculatus* (Fab.) (Coccinellidae). *Lycostomus praeustus* F. (Lyctidae: Coleoptera), *Machimus* sp. (Asilidae), *Adosomyia heminopla* (F.) (Stratiomyidae), *Oecophylla smaragdina* (Fab), *Tetraponera rufonigra* (Jerdon) (Formicidae: Hymenoptera), *Paederus fuscipes* Curtis (Staphylinidae), etc. The exotic coccinellid *Curinus coerulens* was introduced in 1988 for control of the psyllid.

III. PESTS OF SEEDS AND FRUITS

Lasioderma serricorne (Anobiidae) breeds in opium cake, seeds of teak, etc. A number of bruchid beetles attack seeds of *Dalbergia, Acacia, Albizia, Tamarindus indicus,* etc. *Calandra rugiocollis* (Curculionidae) bores the seeds of *Dipterocarpus* spp., *Eugenia, Polyalthia* and *Shorea robusta.* The seeds of *S. robusta* are also attacked by *Diplophyes shoreae* (Curculionidae). The pyralid larva *Hypsipyla robusta* attacks the fruits of *Cedrela toona* (toon fruit borer) in North India.

IV. PESTS OF FOREST PRODUCTS

Product	Pest
Bamboo	*Dinoderus minutus*, *Chlorophorus annularis* (Cerambycidae)
Boxes, chests & plywood	*Heterobostrychus aequalis*
Match veneer & plywood	Powder post beetle, *Lyctus africanus* (Bostrychidae)
Timber Structure	*Xyleborus* spp., *Stromatium barbatum*,
	Camptorrhinus mangiferae (Curculionidae)
	Heterotermes indicola (Rhinotermitidae)

◆ Chapter 75

Medical Entomology

Besides the cultivated crops and the stored crop produce stored, farms, domestic animals, and forest trees, the other important group of life attacked by insects is man himself. Insects attack man in a number of ways. Some simply annoy him and some others directly injure him for his blood while a few, in the process, transmit various kinds of diseases to him.

1. Mosquitoes

Both sexes of the mosquito feed on various juices of fruits and flower nectar but the females take also meals of blood after inflicting a painful bite on human beings. Mosquitoes are well known vectors of four distinct human diseases. The adults of anopheline mosquitoes rest with proboscis and abdomen more or less parallel with surface. Dr. Ross in 1897 demonstrated that the *Anopheles* mosquito is the transmitter of malaria. The principal vectors in India are *Anopheles culicifacies, A. fluviatilis, A. stephensi, A. minimus,* A. *sudanicus, A. philippinensis* and *A. varuna,* out of which the first three species are the major vectors found in South India. *A. fluviatilis* is the main vector in hilly areas and *A. stephensi* in urban areas. Among culicine mosquitoes there are two groups viz., *Culex* group and *Aedes* group. In the *Culex* group eggs are laid in rafts and the siphon tube of the larvae is long. In *Aedes* group the eggs are deposited singly and the siphon tube is short and broad. *Culex fatigans*, found in urban areas in India, is the principal intermediate host of the filarial nematode *Wuchereria bancrofti.* The egg raft of *C. fatigans* is boat shaped with about 200 eggs. Breeding is heavy in waters contaminated with sewage. The transition from egg to adult takes 8-10 days. The exact mode of transmission was described by T.L. Bancroft, who observed that the microfilaria required about 16-17 days in the mosquito before it could reach the infective stage. Human infection occurs at the time of biting. Species of *Mansonioides* are responsible for transmission of *Brugus malayi.* The larvae of this mosquito are associated with aquatic plants like *Pistia* and removal of these plants will at once stop their breeding. Both *W. bancrofti* and *B. malayi* may occur in the same individual. When the mosquito bites a man, the larvae are inoculated into the tissue. The minimum microfilaria density sufficient for infection of mosquitoes is important in order to determine the efficiency of certain drugs like Hetrazan in rendering persons harbouring microfilaria non-infective to the mosquitoes. The minimum number appears to be 3 per c.mm of blood. Monsoon weather is the most favourable one for the transmission of filariasis. Mosquitoes of the genus *Aedes* are responsible for transmission of the causative agents of two important diseases of man viz., dengue and yellow fever. The eggs are deposited singly and the larvae possess a short and broad siphon tube. Graham in 1905 was the first to prove the mosquito-transmission of dengue. In 1906, Bancroft from Australia proved that *Aedes aegypti* (Fig. 75.1) is the carrier of Dengue.

▲ **Fig. 75.1** *Aedes aegypti*

The blood of a dengue patient is usually infective to the mosquito only during the first three days of the disease. The incubation period for the development of the virus in *A. aegypti* is 11–14 days and once infected, the infection lasts during the remainder of its life. *A. aegypti* is also the vector of the disease yellow fever. The infective material of yellow fever circulates in the blood of the patient for the first three days and during this time mosquitoes feeding on the patient become infective. It takes about 12 days before the mosquito is able to propagate the disease to non immunes.

Control: Larvae may be killed by the application of DDT. But as mosuqitoes have developed resistance to organochlorines use of safer chemicals has been taken up. Application of fenitrothion at 0.5 g to 1.0 g a.i. /sq. m. on the surface of mosquito breeding water has been found to be effective up to six and ten weeks, respectively. Fenthion and malathion have also been reported to be effective. Use of mosquito nets of 16 meshes/sq. inch in houses and repellents like citronella oil, etc. may be followed. Commercial products based on DEET (N, N-diethyl m-toluamide) or DEPA (Diethyl Phenyl Acetamide) are available as mosquito repellents. Space sprays of DDT, fenitrothion, fenthion, propoxur, deltamethrin etc. may kill adult mosquitoes, which come to rest on the treated surfaces. Good results have been obtained by impregnating bed nets with deltamethrin 2.5% or lamda-cyhalothrin @ 25 mg/sq. m. or cyfluthrin at 50 mg /sq. m. A water dispersible formulation of *Bacillus thuringiensis* var. *israelensis* serotype H14, strain 164 is highly effective against early instar mosuqito larvae when applied at 0.5 g/sq. m. of water surface or at 0.5% suspension by knapsack sprayer at two to six weekly intervals. *B. sphaericus* is also effective against mosquito larvae. Aerosols for control of mosquito adults include propuxur 0.75% + cyfluthrin 0.025% and cyfluthrin 0.025% + transfluthrin 0.04%. Mosquito mats containing prallethrin 0.5% is also useful as a control measure against mosquitoes.

2. The Housefly *Musca domestica* (Muscidae : Diptera)

The housefly is associated with the spread of the diseases like typhoid fever, cholera, diarrhoea, dysentery, intestinal worms, poliomyelitis, leprosy, anthrax, yaws, etc. The causative organisms of the diseases are picked up by the flies from the human excrements, sputum, carcasses of diseased animals, manure and other filth. They may be carried on the mouthparts, legs, wings and body surface of the housefly.

Control: Keeping the surroundings clean and neat; storing food materials in housefly proof enclosures or boxes, setting baits with milk and formalin for adults flies; surface spray application of propoxur or 125 mg etofenprox is recommended. Aerosols for control of housefly include propuxur 0.75% + cyfluthrin 0.025% and cyfluthrin 0.025% + transfluthrin 0.04%.

3. The Eye-fly *Siphunculina funicola* de Meij (Chloropidae : Diptera)

The minute bluish-black fly generally settles on the face especially on the corners of the eyes of persons with eye complaints and thus cause annoyance. It is commonly seen to congregate in large numbers on threads or ropes hanging from roof in houses in damp warm places. Conjuctivitis is believed to be transmitted by the fly. Surface spray application of propuxur or etofenprox on resting places of the fly may be useful.

4. Sand flies *Phlebotomus* spp. (Psychodidae : Diptera)

The flies are small with the body and wings thickly covered with hairs. The females of Psychodinae are blood-suckers and transmit kala-azar disease caused by *Leishmania*, a flagellate which is spread by *Phlebotomus argentipes. P. pappatasi* transmits the Pappatasi fever prevalent in India. Verruga disease in Peru is transmitted by a species of *Phlebotomus.*

5. The *Simulium* or Black flies (Simuliidae : Diptera)

The females are vicious biters and suck blood mostly of cattle. Some species attack man. Eggs are laid on aquatic plants submerged in water. The larvae occur in swiftly running streams fixing themselves to stones or plants at about 30 cm depth. Human onchocerciasis caused by the nematode *Onchcerca volvulus* is transmitted by *Simulium damnosum.* The disease occurs in tropical Africa, Arabia, and central America. *Simulium indicum* is troublesome in Himalayas.

6. Bed bug *Cimex hemipterus* (Cimicidae : Hemiptera)

The venom introduced by the bed bug bite causes itching, burning and swelling. They are parasitic on man and suck his blood. A large number of diseases like relapsing fever, typhus, kala-azar, plague, leprosy, etc. have been suspected of being carried by bed bugs but not proved. A female lays about 50 eggs singly in about four months in cracks, crevices, furniture, mattress, pillows, etc. The egg is white and flask-shaped. The incubation period is four to five days during summer and 10 days during winter. The bed bug feeds intermittently by sucking blood from man. There are four nymphal stages, each stage lasting for five to seven days. The bed bugs are disseminated mainly through the agency of personal clothing. *Cimex hemipterus* is the principal species in the tropical countries and *C. lectularus* in the temperate countries (Fig. 75.2).

▲ **Fig. 75.2** *Cimex lectularius*

Control: White washing and closing the crevices of walls, application of boiling water on furniture which can withstand high temperature, and surface spray application of fenitrothion, propoxur, etc. may be useful in controlling bed bugs.

7. The Assasin bug *Conorhinus rubrofasciatus* (Reduviidae : Hemiptera)

It is also known as Cone Nose bug or Kissing bug. It is dark brown, 20-24 mm long and is found hiding in crevices or under stones. It attacks both man and other insects. The pain caused to human beings is intense and swelling generally follows. Fainting, vomiting and other ill effects may be experienced. Usually they bite man at night for blood meal. Collection and destruction of the bugs may be done.

8. Fleas *Pulex* spp. and *Xenopsylla cheopis* (Pulicidae : Siphonaptera)

Fleas in their adult stage live as ectoparasites of warm-blooded animals. They infest dogs, cats, human beings etc. Its bite is not felt at once but becomes increasingly irritating and sore over several days. Bubonic and septicaemic plague is the principal disease carried by rat flea, *X. cheopis.* The causative organism of plague is the bacillus *Pasteurella pestis. Xenopsylla cheopis* is widely distributed in the tropics and in India it is widely prevalent in the plains and also in the hilly regions. *X. brasiliensis* is another plague flea found in India and Africa. *X. astia* is also prevalent all over India. *Pulex irritans* is essentially a human flea and *Ctenocephalides canis* and *C. felis* are dog and cat fleas, respectively. The flea is apterous and its body is heavily chitinised and laterally compressed. *X. cheopis* and *X. astia* lay about six to eight eggs after a blood meal and the eggs are deposited in places where the host rests. A female lays about 200 eggs in her lifetime. The larvae feed on a variety of organic material. The flea is parasitic only in its adult stage. Both the sexes feed on blood and may leave the host between feeds. Only during an epizootic of plague among rats they attack man.

Control: Dead rats should not be handled and should be burnt by pouring kerosene. The breeding places should be treated with propoxur for controlling the fleas.

9. Human body louse *(Pediculus humanus humanus)*and Head louse *(P. humanus capitis)* (Pediculidae : Siphunculata)

Both the lice can transmit relapsing fever, epidemic typhus fever, French fever, etc. They also cause lot of irritation by their bites. The skin becomes scarred, thickened and bronze-coloured with brownish spots. The head louse is found on the skin and among the hairs of the head. It glues its oval, pearly-white, eggs singly to hairs. The body louse is found in the clothing and lays eggs in seams of the clothing. About 300 eggs are laid by a louse.

Control: Hair must be combed and lice collected and killed. The infested head should be treated with pyrethrin in pyrophyllite or commercial preparations such as Kenz containing gamma HCH.

◆ Chapter 76

Veterinary Entomology

As if they are not content with the damage they cause to growing crops and stored crop produce, and with the various diseases they transmit to crops cultivated by man, insects attack all animals domesticated and reared by him. This variety of insect pests not only cause direct injury and annoyance to these animals but also, in some cases, cause and transmit diseases and functional disorders in them. The productivity of the affected animals is impaired and the utility of farm animals is reduced resulting in huge aggregate yearly losses. The insect pests of cattle and other domestic animals are mostly members of Diptera and some are of Mallophaga, Siphunculata and Siphonaptera. They attack cattle, sheep, goats and fowl.

I. CATTLE

1. THE HORSE FLY *Tanbanus striatus* F. (Tabanidae : Diptera)

It resembles the housefly but is larger and stouter, has three rows of white spots on the abdomen and prominent compound eyes, almost contiguous on the vertex in males. The fly breeds in marshy places. Eggs are black and elongate, spindle-shaped and are glued in masses to aquatic plants. The maggots are elongate, spindle-shaped and carnivorous; they drop to the substratum where they live feeding on small aquatic organisms. The female fly pierces the skin of animals and suck the blood, which continues to ooze from the wounds even after the fly has left the animal. The male feeds upon nectar of flowers. On an animal 50 or more tabanids may be found in an hour. Life cycle is four to five months and there are two to three broods in a year.

2. THE STABLE FLY *Stomoxys calcitrans* (L.) (Muscidae : Diptera)

It is a cosmopolitan species. The grey fly can be distinguished from the houseflies by its somewhat smaller size, long proboscis adapted to pierce the skin and seven spots on the abdomen. It breeds in moist straw, grass and other material in the cattle shed, to which urine and dung of the hosts get added. The fly is usually abundant after rain. Both females and males suck blood from cattle, horses and other animals including man, usually from his legs and get engorged in two to five minutes and may feed as often as twice a day. A female lays 600-800 eggs. Its life cycle occupies 10-14 days.

3. THE CATTLE FLY *Hippobosca maculata* L. (Hippoboscidae: Diptera)

It is a flat fly with a leathery thick-set body and strong tarsal claws. It can always be seen on cattle clinging mostly at the sides of the neck region. It feeds on the blood continuously and produces seed-like puparia directly, without laying eggs or larvae; the puparia drop to the ground and adult flies emerge in a week.

All the above three flies can be controlled by use of deterrents. Application of fenitrothion 50 % EC @ 100 ml in 10 litres of water or deltamethrin 2.8% EC @ 2 ml/litre water has been reported to be effective. The animals may be sprayed individually taking care to treat the tip and under portion of the tail; inside the ear and folds of legs. For prolonged residual effect washing of the animals should be avoided for a few days after the spraying. Spraying may be repeated at an interval of four to five weeks.

4. THE BLOW FLY OR BLUE BOT FLY *Lucilia serenissima* E. (Calliphoridae: Diptera)

It is a metallic blue or green coloured small fly whose larvae attack open wounds and sores of cattle and feed on decaying tissues. It also bores into flesh causing cutaneous myiasis and other internal complications. At times they may be useful because they clean wounds of dead tissues.

5. THE OX WARBLE FLY *Hypoderma lineatum* (deV.) (Oestridae: Diptera)

The female fly lays eggs glued to the hairs near the hooves in cattle. They hatch in two to three days and the maggots penetrate into the skin tissues and live for several weeks. They move to oesophageal wall and then reach the subcutaneous tissue on the back of the animal where they form tumour-like swellings or warbles. The skin of the warble is perforated by the larvae for respiration and later through these holes the full-grown larvae fall to the ground for pupation. Adult flies emerge after three weeks. As the skin is drilled and bored, the hide becomes unmarketable. The fly can be controlled by washing the warbles with water infusions of lime and tobacco.

6. THE HOUSEFLY *Musca* spp. (Muscidae : Diptera)

Out of the many species of *Musca* a few are blood sucking and the rest are non-biting but are of considerable nuisance value to animals. *Musca domestica* L., *M. nebula* F., *M. vicina* Macq., and *M. sorbens* Weld. are non-biting flies. The fly breeds in a number of decaying material including cattle dung and night soil. A single female lays up to 200 eggs during her life span and the eggs hatch within about three hours. The full-grown maggots pupate in damp soil. The houseflies are carriers and intermediate hosts of many cattle diseases. Another species of *Musca* viz. *M. crassirostris* Stein is haematophagous, breeding on cattle dung, biting and sucking blood from cattle. The spray schedule suggested for control of the cattle fly may be useful against this fly also. Spray of etofenprox 10 EC @ 125 mg a.i./ sq. m. in cattle shed is effective against adults.

7. THE BLOOD-SUCKING FLY *Siphona exigua* de Meijere (Muscidae: Diptera)

It is a common blood-sucking fly in India, which attacks cattle, buffalo and dog. It is attracted by the odour, warmth and sweat of its host. Both sexes are blood suckers. The fly lays eggs in fresh cow dung and a female lays about 20 eggs. The incubation period is about 10 hours. The maggot becomes full-grown in about seven days and pupates in the soil some distance away from the dung. The adult fly emerges in four to five days.

8. SAND FLIES *Phlebotomus papatasi* (Psychodidae : Diptera)

Sand coloured females of *Phelbotomus* suck blood. Each female lays about 30 eggs in damp places. Incubation period is about 10 days. Larval stage lasts for 20 to 50 days and the pupal stage for a week. Species of these flies are known to transmit various diseases like kala-azar or leishmaniasis in man.

9. THE EYE FLY *Siphunculina funicola* de Meij. (Chloropidae: Diptera)

They are shining black in colour usually seen clinging in clusters on hanging strings in houses and cattle sheds. They hover in front of the eyes and feed upon the secretions from the eye. They breed in moist soil and faecal matter.

10. EYE FREQUENTING MOTHS

A few moths are known to frequent the eyes of vertebrates and mention may be made of the following. The moths of *Arcyophora icterica* (Noctuidae) frequent the eyelids of cat, cattle, waterbuffalo, horse and donkey in South India and feed on lachrymation and pus. The moths of another species *Pionea damastesalis* Walker (Pyralidae) are known to visit the eyes of cattle, waterbuffalo and elephant and also that of man for feeding on lachrymation, besides feeding on fluid running down the cheeks of the animals.

In addition to the above insect pests, females of various species of the stout black gnats (Simuliidae : Diptera) which breed in swift running water streams, the mosquitoes

(Culicidae : Diptera) and the midge, *Culicoides* sp. (Ceratopogonidae : Diptera) annoy cattle and suck blood from them.

II. FOWL

1. THE SHAFT LOUSE *Menopon gallinae* (L.) (Menoponidae : Mallophaga)

It is a permanent ectoparasite of fowl found on their feather feeding by nibbling on the dry scales of the skin and chewing the feathers. Badly infested birds can be observed rubbing their bodies in soil or ash pits to get rid of the annoyance caused by these lice. The louse is small, wingless, very active, greyish brown in colour with a hard and horny body with mandibulate mouthparts. The eggs are fastened to the basal barbs in large numbers. The yellowish nymphs hatch out in two weeks. They become adults in 10- 12 days. The louse spends its entire life cycle on the host bird itself.

2. THE BODY OR VENT LOUSE *Menacanthus stramineus* (Nitz.)(Menoponidae : Mallophaga)

It is one of the commonest ectoparasites of poultry. It congregates on the skin just below the vent and in cases of severe infestation may be present on the ventral side under the wings. It is very destructive.

3. THE WING LOUSE *Lipeurus caponis* L. (Philopteridae : Mallophaga)

It infests the underside of the primary feathers and does not move about a great deal.

4. THE CHICKEN FLEA *Echidnophaga gallinacea* (W). (Tungidae : Siphonaptera)

The flea infests the face, comb, wattles and area around the eyes of fowl in clusters. Sometimes hundreds of these insects may be seen on a single bird. When heavily infested young birds die and older ones get emaciated. It is a minute, flat, dark brown insect remaining attached to the host with its head embedded into the skin of the host, so that it is not easily brushed off. The eggs of the flea drop to the ground where the larvae develop in the filth. Only the adult fleas attack the birds.

Control: For the control of poultry lice and chicken flea spray application of the birds in batches of 10- 12 birds at a time with fenitrothion 0.25 per cent solution to the point of drenching has been found useful. The spraying should be repeated at intervals of three months. Care should be taken to avoid contamination of poultry feed and water.

5. THE MOSQUITOES *Aedes aegypti* (L.) (Culicidae : Diptera)

It transmits malaria in fowls caused by *Plasmodium gallinaceum.*

6. BED BUG *Cimex hemipterus* Fab. (Cimicidae : Hemiptera)

The bugs suck the blood from the birds at night. Both adults and nymphs feed on the birds and cause loss in egg production as the birds get emaciated. Spraying the infested premises with 0.5 % fenitrothion or deltamethrin 25 ppm controls the pest. There is no need to spray the birds as the bug attacks the birds only at night. The spraying should be repeated after about three weeks.

III. SHEEP AND GOATS

1. THE HEAD MAGGOT OF SHEEP *Oestrus ovis* L. (Oestridae : Diptera)

This larviparous fly deposits the maggots in the nostrils of sheep. The maggots move to frontal sinuses resulting in constant nasal discharge and sometimes obstruction of air passages in the affected sheep. In serious infestations the sheep may die.

2. THE SHEEP KED *Melophagus ovinus* L. (Hippoboscidae : Diptera)

It is a wingless, leathery, hairy fly attacking the sheep in different parts of our country. The female glues its larvae to the wool of sheep. They soon turn into pupae. The adults live among the wool and suck blood causing intense irritation prompting the sheep to bite the area thus damaging the wool. Spraying with 0.01 % diazinon or deltamethrin 25 ppm will eliminate the ked.

3. THE BITING LOUSE *Bovicola caprae* (G.) (Trichodectidae : Mallophaga)

Commonly occurs in goats and *B. ovis* in sheep. Dips containing 0.01 % diazinon or deltamethrin 2.8% EC @ 3 ml litre water i.e. 37.5 ppm can be employed for controlling these lice.

General Control Measures

The treatment solution should be prepared just before use. A quantity of 3.5 litres may be required to make a medium size cattle fully wet. For dogs the hand spray can be used or its body rubbed with a cloth dipped in the solution. Spray the recommended chemicals in poultry sheds, stables and farm houses for ectoparasitic control. One litre of spray fluid should suffice for 20 sq. m. area.

◆ Chapter 77

Insect Pests of Household

Insects are known to frequent our dwellings, fall accidentally into our eyes, rest on sensitive parts of our body, make irritating noise and damage our food materials, cloths, carpets, furniture, books etc. due to their biting and feeding and cause annoyance to us. The following are some of the household insects.

1. ANTS *Monomorium criniceps* and *M. destructor* (Formicidae : Hymenoptera)

The former is a small brown ant and the latter is a small red ant. Everyone is familiar with the house ants, which carry bits of our food materials to their nests. There are also some species which are injurious because they build nests in the sills and wood work of houses. The species that are found in lawns and walks in our house gardens throw mounds of earth about the entrance to their nests and thus disfigure the lawn. Some species feed on seeds, fats, dead insects, etc.

Control: Ant pans can be used where ever feasible. Dusting carbaryl 10 % or spraying 2 to 5 % solution of chlorpyrifos in deodorised kerosene in infested area may afford relief. Poison baiting with thallium sulphate bait for sweet loving ants and with thallous sulphate bait for protein loving ants may be useful.

2. TERMITES

Termites feed on wood, paper, wood products, dried plant and animal products, etc. Among termites we have the soil inhabiting forms and the wood inhabiting forms, the later damaging dry and damp woods. To prevent infestation by subterranean termites, having any wood work of buildings within 40 cm of contact with the ground should be avoided. A thin sheet of metal or good concrete between the foundation and timbers of the house will prevent infestation. Termite proofing of wood can be done by pressure impregnation with coal tar, creosote, zinc chloride, mercuric chloride, sodium fluosilicate, chlorpyrifos, lindane etc. after the wood is cut. Soil poisoning with chlorpyrifos in kerosene may be done. For protection of wood and buildings (pre/post construction) from termites attack lindane 20% EC or chlorpyrifos 20 EC @ 250 ml diluted in 5 litres water is applied.

3. POWDER POST BEETLES

The furniture beetle *Sinoxylon sudanicum* (Bostrychidae: Coleoptra) and some other species of Lyctidae, Ptinidae, Anobiidae and Bostrychidae are also destroyers of wood. The grubs cut the hard and dry wood tunneling through timbers in successive generations until the interior is completely reduced to fine packed powder. Small shot holes are visible externally. They are often responsible for destruction of timbers of buildings, log cabins, furniture, tool handles, etc.

Control: Wood may be preserved by treating it with copper sulphate or zinc chloride. Drying the wood at 82°C for half an hour kills the insects. Fumigation with methyl bromide can be done where ever feasible. Painting the wood with varnish, paint, tar, etc. keeps the wood free of attack.

4. SILVER FISH *Ctenolepisma* sp. (Lepismatidae : Thysanura)

The insect is found commonly in neglected places on walls. It feeds on a large variety of materials such as starched clothes, rayon fabrics, bindings of books, papers on which paste or glue has been used, etc. The insect is wingless, 8 - 13 mm long, silvery greenish grey or brownish and sometimes faintly spotted; lives in warm places and avoids light. The eggs are deposited loosely in secluded places and the incubation period may be about a week. The adult stage is reached in 3 to 24 months. The insect can be controlled by surface spray application of propoxur at 0.5 % strength. Poison baits consisting of oatmeal, sodium fluoride or white arsenic, sugar and common salt may also be useful.

5. COCKROACH *Periplaneta americana* (Blattidae : Dictyoptera)

The cockroach is a common insect found in almost all houses. The insect is flat, brownish and foul smelling. It is active at night or in dark basements and feeds on bindings, magazines, paper coverings of boxes, various food products in kitchens, bakeries and restaurants and produces foul smell with the excreta spread over. The female cockroach produces an ootheca once in four or five days and 15 to 90 oothecae may be laid. Each ootheca contains 14 to 16 eggs and the incubation period ranges from 15 to 100 days. The nymphal period occupies 10 to 16 months. Dust of propuxur, a carbamate insecticide, if spread all over infested places, affords effective control of cockroach. Surface spray application of propuxur is also effective. Etofenprox (1 mg per sq. cm.) spray application is highly effective against German cockroach *Blattella germanica* (Fig. 77.1). Scrupulous cleanliness to keep away the insect is essential. Deltamethrin 0.5% w/w attractant tablet for cockroach has been developed. Aerosols for control of cockroaches include propuxur 0.75% + cyfluthrin 0.025% and cyfluthrin 0.025% + transfluthrin 0.04%.

▲ **Fig. 77.1** *The German Cockroach Blattella germanica*

6. CARPET BEETLE *Anthrena pimpinella* (Dermestidae : Coleoptera)

The larvae and adults of the beetle bite holes in fabrics like wigs, clothings, curtains, interior padding of furniture, etc., which contain especially wool, fur, feathers and hairs. They also attack cotton goods, silk, insect specimens, stuffed animals, dried meat, etc. The eggs are deposited in dark secluded places or on fabrics. The larva possesses erect, brown or black hairs all over its body. Regular cleaning of materials is essential. Godowns where fabrics and other material are stored should be fumigated. In small enclosures or boxes use of paradichloro benzene crystals or napthalene balls may give relief.

7. CLOTHES MOTHS *Trichophaga abruptella* (black and white moth) and *Tinea pachyspila* M. (brown moth) (Tinaeidae: Lepidoptera)

The larvae attack mainly wool, hair, feathers and furs and sometimes damage dead insects, dry dead animals, animal and fish meals, milk powders, leather, etc. The control measure suggested for carpet beetle may hold good for this also.

8. CRICKET *Gryllus* sp. (Gryllidae : Orthoptera)

The crickets live in the crevices and the males mainly cause annoyance by making chirping noise at night by rubbing the wings together. They can be easily located, collected and destroyed.

◆ Chapter 78

Insect Vectors of Plant Diseases

Insects are involved in the transmission of bacterial, fungal, viral and phytoplasmal diseases of plants, besides affecting humans and animals in serving as agents in the transmission of diseases. Transmission may be *mechanical,* the organism being borne on the surface of the body of the insect, usually the mouthparts. Transmission may be *circulatory* when the organisms are ingested by the insect, circulate in the body and are later discharged in the salivary fluids. Transmission may be by *inoculation* in the case of sucking insects where through a wound made by the insect, the pathogens invade the tissue. The relationship may be *obligate* when the pathogens are transmitted by inoculation or *facultative* wherein the pathogens can be transmitted in other ways. In short, an insect whose feeding produces symptoms of disease is termed *toxicogenic* and the condition is called *phytotoxaemia.* Insects, which transmit disease organisms are called *vectors* and a variety of insects, mostly with sucking mouthparts may serve as vectors of plant diseases.

The insect vectors provide a versatile means of spread achieving an effective distribution of inocula. The modus operandi of exploitation by vectors is essentially achieved by their polymorphism which involves the production of diverse adult forms of contrasting behaviour, such as alate/ aptera, or macroptery/brachyptery/microptery, colour diversity, sex-limited polymorphism and biotic potential, besides the comparative ability of both sexes and morphs to transmit the virus. The role played by seasonal, photoperiodic endocrine and crowding phenomena in the production of different forms, notably in aphids is an aspect that has to be recognised, more in view of the vector role of aphids. Operation of switch mechanisms induced by photoperiodic responses and endocrine influences produce sexual/ parthenogenetic and alate/ apterae respectively, besides the maternal switching mechanisms wherein generations of parthenogenetic viviparae have embryos telescoped. Moreover within every species a range of biotypes exists, each with its own vector capacity, responding differently to environmental stimuli and have the capacity to settle on different plant genotypes besides their different nutritional requirements enabling them to respond differently to host plants.

Many cicadellids feed on cereals and grasses and have two contrasting types of spreads i.e. the long fliers with short bodies predominating the main flight period, and short fliers with relatively long bodies. Short-bodied forms are less fecund. Field populations are known to have a balance of long bodied poor fliers suited for dispersal to favourable habitats. This type of structural and behavioural polymorphism has obvious survival value for leaf hoppers facilitating colonisation and subsequent exploitation provides an efficient means of virus spread.

When a virus is widespread in several crops and perennial plants, and when spread by several vectors such as aphids, the complexity of the ecological interactions become great. For e.g., *Rhopalosiphum maidis, R. padi, Schizaphis graminum,* etc. which are major vectors colonising cereals have different biologies. For instance one may be monoecious and holocyclic, another heteroecious and heterocyclic, and the third may be anholocyclic. In *R. maidis* four different biotypes are known with varied ability to transmit the virus and these have different modes of virus spread depending on the physiological status of the insect vector. These different types of virus spread lead to different patterns of spread requiring a different management strategy.

Even colour differences have their own impact as for instance the pale form of the thrips, *Frankliniella schultzei,* the vector of TMV is not being able to transmit the virus, unlike the darkened forms. Colour morphs of several aphid species, which can range from green to brown, passing through a range of pink and red, have shown green forms to be more fecund with high rates of parasitism. Hence without an understanding of the structural and behavioural diversity of vectors, their movement, their ability to travel, their feeding and reproduction and what cause them to settle down, feed and reproduce, it would be difficult to explain the progress of epidemics, so that merely designating a species as a vector is often misleading. Therefore, there is great need to understand the occurrence and significance of biodiversity within vector populations. A basic factor is that colonising forms are partially active, seldom settle down to feed and reproduce until dispersal has occurred.

Infected plants are known to be attractive or palatable to vectors and this stimulates increased multiplication and crowding. This follows movement from crowded populations that develop on ripening crops, weeds and other wild plants, as these begin to senesce.

Long range viral dispersal occurs in such circumstances, so that a close association between virus spread and migration exists, and thus the breeding population gets transferred to fresh sites before original site becomes unpalatable. The relationship between the insect vector and the host plant of the virus needs to be understood. The diseased plant being an altered host, little is known of specific changes occurring in plant cultivars, under insect feeding stress and their subsequent effects on vectors. Increased amino acids in infected plants/senescent plants may be detrimental to some and in response to deterioration of host quality nitrogen (N) levels fall resulting in the production of alates in aphids, which migrate to secondary hosts. Some viruses that replicate in the vectors have shown much deleterious effects on fecundity/longevity that they are likely to impair mobility and flight performance. It is important to monitor the distribution and spread of vector biotypes, as increasing number of vectors develop tolerance to pesticides and overcome host plant resistance mechanisms.

Non-culturable plant infecting molecules are designated as Phytoplasmas (mycoplasma-like organisms) and are grouped in between viruses and bacteria. They are without a visible cell wall, whose place is taken by a thin elastic cytoplasmic membrane, which cannot withstand osmotic pressure. They are pleomorphic and may be spherical or oval, varying from 80-800 microns in diameter.

An aspect of interest relates to thrips - fungal interactions, wherein sex-limited polymorphism plays an important role in the increased mechanical transfer of pathogenic fungal spores to many forest plants. The array of male polymorphs from the gynaecoid to the oedymerous males enable transport of spores of pathogenic fungi such as *Anthostomella, Pestalotia, Malanographium, Phomopsis* and *Lasiodiplodia* to sites of infection.

In view of the very large number of plant diseases caused by insect vectors, the table presented provides information on the more important ones.

Diseases	*Vectors*	*Host plants*
1. Virus diseases		
Cucumber mosaic	*Myzus persicae*	Cucumber and weed plants
Sugarcane mosaic	*Rhopalosiphum maidis*	Sugarcane, Sorghum, corn, millet
Spotted wilt	*Thrips tabaci*	Tomato
Tomato mosaic virus (TMV)	*Frankliniella schultzei*	Tomato
Potato leaf roll	*Myzus persicae*	Potato and other solanaceous plants
Cowpea mosaic	*Aphis gossypii*	Cowpea
	Aphis craccivora	Cowpea
Banana Bunchy top	*Pentalonia nigronervosa*	Banana
Cardamom mosaic ('Katte' disease)	*Pentalonia nigronervvosa*	Cardamom

Diseases	***Vectors***	***Host plants***
Papaya mosaic	*Aphis gossypii*	Papaya
	Aphis craccivora	Papaya
Chilli mosaic	*Aphis gossypii*	Chillies
Vein clearing disease	*Bemisia tabaci*	Lady's finger (Okra, Bhendi)
Dolichos Yellow mosaic	*Bemisia tabaci*	Lab-lab bean
Tobacco leaf curl	*Bemisia tabaci*	Potato
Tomato leaf curl	*Bemisia tabaci*	Tomato
Papaya leaf curl	*Bemisia tabaci*	Papaya
2. Phytoplasma diseases		
Rice yellow dwarf	*Nephotettix virescens*	Rice
'Little leaf' disease	*Cestius phycitis*	Brinjal
Sesamum phyllody	*Orosius albicinctus*	Sesamum (Gingelly)
3. Fungal diseases		
Ergot of Cereals *(Claviceps purpurea)*	Many flies	Cereals
Ergot of Bajra *(Sphacelia macrocephala)*	Insects	*Pennisetum typhoideum*
Cotton wilt *(Fusarium vasinfectum)*	*Melanoplus differentialis*	Cotton
4. Bacterial diseases		
Bacterial wilt of corn (Stewart's disease)	Flea beetles *Chaetocnema pulicaria , C. denticulata*	Corn
Cotton boll rot (*Bacillus gossypiana)*	Hemiptera	Cotton
Cucurbit wilt	*Erwinia*	Cucurbit

Section Nine

Methods and Principles of Pest Control

◆ Chapter 79

Integrated Pest Management

Insect control programmes aim at avoidance, elimination or reduction of the factors, which promote excessive multiplication of insects. For the efficient functioning of insect control measures, a thorough knowledge of their life cycles, their pest status, distribution, periodicity, host-complex, behaviour among others, is a prerequisite, essential for timing of the controls. As the economics of the control methods adopted is equally vital, any measure devised has to be practical, cheap and effective.

It is usual to broadly classify insect control methods into the natural and applied or artificial control methods. As has already been discussed under population dynamics, natural control methods involve such factors as climate including in it directly or indirectly the effects of temperature, humidity, rainfall of a region, soil conditions and nature of wind currents; topographic factors, including barriers like mountain ranges, large bodies of water, thick forests restricting the spread of insects; and natural enemies like the predators and parasites which increase with the increase of populations of insect pests.

Applied or artificial control methods are mostly divided into the preventive and curative or direct methods. Preventive or prophylactic methods to ward off pest invasions include measures such as the removal of weeds, grasses and dead branches from fields; through usage of good seeds, proper cultivation, manuring, irrigation, removal of crop remains and stubble, growing of pest resistant varieties, treatment of seeds with chemicals, rotation of crops, mixed croppings, changing of the sowing, planting and harvesting times, cutting and raking of field bunds etc. Among the direct methods are the physical and mechanical methods. The physical methods involve the use of electricity, sound waves, infra-red and X-rays. The mechanical method is concerned with the operation of machinery such as hopper dozers, fly and maggot traps, light traps, centrifugal force machines (entolete) for stored grains and manual operations involving the hand picking of egg masses, larvae and adults. Chemical methods include the use of insecticides, repellents and attractants, antifeedants and chemosterilants. Another aspect of control is the legal or legislative method. In order to prevent the introduction of exotic pests, diseases, weeds, etc. with a view to help in the prevention of their spread within the country, special acts or laws are enforced. In addition to prevention of spread of pests, they also serve to help in the correct determination of insecticidal residue tolerance in food stuffs, in the prevention of adulteration and misbranding of insecticides and regulate the activities of pest control operations, particularly in the application of hazardous insecticides. It may be of interest to point out that the then Madras State (presently Tamil Nadu) was the first to enact the Agricultural Pests and Diseases Act in India in 1919 for the control of the black-headed coconut caterpillar (*Opisina arenosella*), the cottony cushion scale (*Icerya purchasi*), the coffee borer (*Hypothenemus hampei*), the sugar cane top borer (*Scirpophaga excerptalis*), the cotton boll worm (*Earias* spp. and *Pectinophora gossypiella*), the red hairy caterpillar (*Amsacta albistriga*) on groundnut and the coffee stem borer (*Xylotrechus quadripes*).

The need for a reduction in the use of pesticides in view of environmental and health concerns, besides a more effective insect pest management, led to the emergence of a new perspective in pest control called Integrated Pest Management (IPM). It aims to make crop production more efficient, while seeking protection from misuse of pesticides. In this context, populations of insects are monitored and pesticides applied only when and where they are needed to control specific insects in specific crops at specific times. In a broad sense IPM has been defined as "the optimisation of pest control in an economically and ecologically sound manner, accompanied by the coordinated use of multiple tactics to assure stable crop production and to maintain pest damage below the economic injury level, while minimising the hazards to human, plants and environment". IPM must be visualised in terms of agroecosystem management with farms considered as ecosystems. A better understanding of factors affecting ecosystem stability, population dynamics of pest species and the ability of population to recover from stress are important. IPM is a challenging issue, which needs to look into new techniques, new management skills, and new concepts of integration to control insect pests of crops, protect the environment and provide continuous and abundant food supply. For this multidisciplinary research involving an integration of crop physiologists, entomologists, bio-meteorologists and biochemists becomes important. The success of any effort to develop IPM system is also based on maximising the impact of biological control agents, with industries cooperating to adopt reduced sales of broad spectrum insecticides, as well as market more selective compounds and formulations. It is because of the reluctance to change in this manner that IPM has suffered. The introduction of farmers' cooperation and active participation by agrochemical industry besides research organisations would help overcome this impasse.

The development of IPM programmes involves three phases viz., problem definition, research and implementation. The choice of control measures for IPM is essentially determined by two important aspects, the type of pest involved and socio-economic concern affecting the availability of various control products and techniques.

The definition phase requires a large number of inputs and should have a comprehensive approach based on a threshold framework to insect pest management, enabling integration of the various components formulated by different research groups. Integration can take place only when there is an appropriate institutional framework.

In the light of the above general aspects of IPM some examples would throw better light into the operational aspects. Taking the rice gall midge management, an IPM approach consisted of cultivation of resistant varieties, cultural practices like stubble destruction, early planting of susceptible varieties, judicious use of nitrogenous fertilizers and application of granules of phorate or carbofuran in nurseries. Select a pest resistant variety, adjust sowing/planting time in such a way as to avoid the crop's vulnerable stage with peak period of insect multiplication. Monitor the nurseries and apply insecticide only when the pest population is moderately heavy. Adopt cultural practices like optimum spacing, optimum nitrogen fertilizer application, sanitation of crop; monitor pest population or damage at seven to ten day intervals. Disperse or delay insecticidal use when the population of natural enemies is abundant.

In the case of other crops like sorghum, vegetables, etc. cultural practices and pest resistant cultivars should be exploited in IPM. Botanical insecticides such as Azadirachtin from neem (*Azadirachta indica*), *Vitex negundo*, *Pongamia glabra*, etc. should be exploited in pest control. Cropping system and cultivars that encourage natural enemies should be identified and fitted into pest management programmes. In the cotton ecosystem, the over and misuse of insecticides resulting in failure of control of the bollworms due to development of resistance to insecticides and resurgence of sucking pests are well known. Semiochemicals aiding in insect communication appear to be promising, since they tend to disrupt normal activity of insects. The pheromone Gossyplure effectively interferes with the mating of the cotton pink bollworm *Pectinophora gossypiella* and when it is applied alternately with selective insecticides yield of seed cotton increases. The IPM programmes implemented in cotton are such that they involve carefully selected methodologies, after taking into consideration the ecological aspects of the crop and its socio-economic impact.

The fact that biological control agents are competing with chemicals cannot be ignored and in the near future IPM will depend upon the availability of select chemicals to integrate with. The efficiency of traditional natural control can be enhanced by using biopesticides and pheromones. Castor is traditionally used in mixed crop plantations forming an active part of IPM.

Stacking genes or adding multiple types of toxin-coding genes to crops and replacing toxin-coding genes at regular intervals are all recent strategies in IPM. These are tested on the cotton bollworms with a view to build up greater stock of predators and parasitoids for better natural control. Control methods can be applied at various periods in the life cycle of the insect–mating, egg laying, larva, pupa and young and old adults. Through blocking the production of pheromones, release of sterilised males, interfering with neuropeptide function, etc. it is possible to prevent egg laying. Baculoviruses are ideal candidates in IPM because of their high degree of specificity and safety to beneficial parasitoids and predators and pollinators. Many of these baculoviruses cause epizootics and collapse of insect population, and spraying them in an early outbreak cycle accelerates collapse. Further, baculoviruses can be mixed with a variety of chemical pesticides including fungicides and insecticides as well as microbial agents such as Bt *(Bacillus thuringiensis)*. When larvae die from NPV (*Nuclear polyhedrosis virus*) or GV (Granulosis virus) infection, their bodies release large quantities of occlusion bodies on to the host plant resulting in horizontal transmission and a secondary cycle of infection.

Needless to emphasise that IPM is not an easy operational programme to achieve and what little is known does not involve all the aspects needed for a holistic approach. For instance, the necessity to understand the relation between weather, insect population dynamics damage to crops, yield loss and economic application of insecticides along with biocontrol agents or biopesticides is of paramount importance. If the interaction of natural enemies and the effect of agronomic practices or use of resistant cultivars are not included, then IPM becomes incomplete. All the same when all these aspects are included, the situation would be a complex one wherein it will be difficult to evaluate the role of each interaction. What is needed is the assembling and formulating of a conceptual model wherein the different components are identified with a better specification of their interrelationships.

◆ Chapter 80

Biological Control

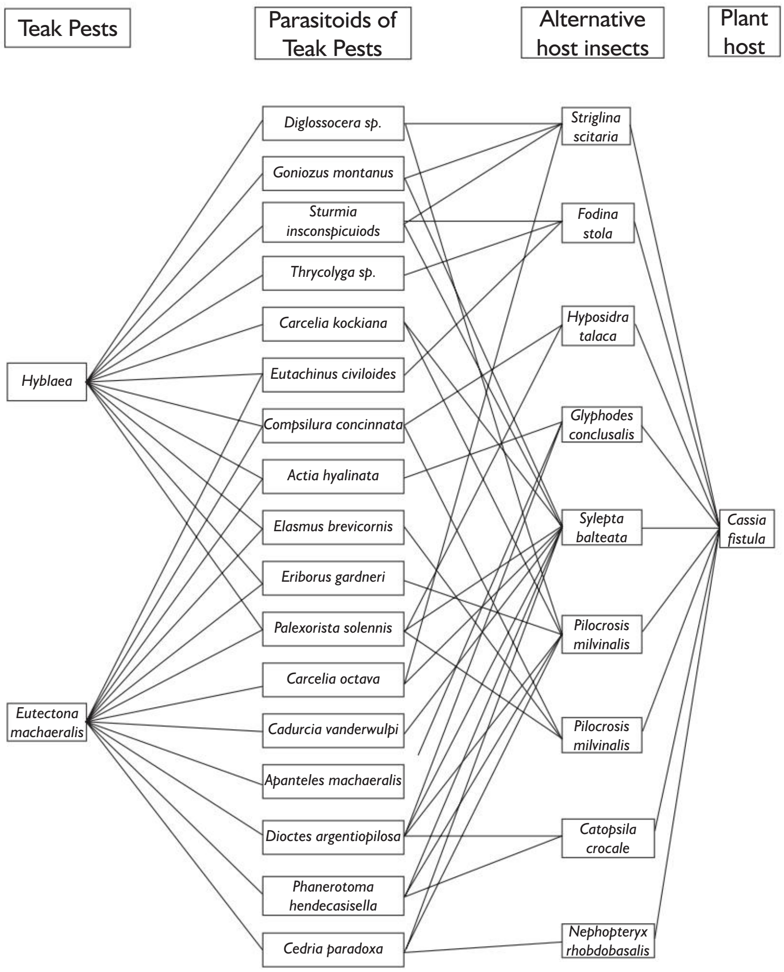
With the development of recent trends swinging towards population and population dynamics, studies on biological control methods have taken new dimensions and has, therefore, became a special field called "Applied Ecology," overlooking earlier attempts at defining it merely as the utilisation of parasitoids and predators in the control of insect pests. As defined in the context of our knowledge of population ecology, it is well known that in any population of insects there is a state of inherent stability in an ecosystem. Hence biological control is concerned with the environmental factors affecting the regulation and stabilisation of population of insects. The stability of populations in an ecosystem is termed "homeostasis." The most essential feature in biological control is the determination of the pest status of a species after a prior knowledge of the extent and the manner in which this homeostasis is disturbed. By colonising natural enemies available locally or by importing them from the countries of their origin, it is possible to ascertain how they disrupt the stability or position of equilibrium of the pest to a non-economic level and help in maintaining this level. By so regulating the pest populations, biological control plays an important part in insect control programmes. Ethology (behavioural aspects) is of importance in biological control studies in view of the data obtained regarding the behaviour of insects to their food source and hence in host selection. A correct knowledge of the centers of origin and distribution of the natural enemies as well as a proper taxonomic assessment are essential criteria in solving problems of biological control (Fig. 80.1).

The principal methods employed in biological control include:

(a) collecting parasitoids and predators from places of their origin and releasing them in places where they are absent;

(b) collecting and storing the host insects in such a way as to kill them, but permitting the parasites to escape;

(c) rearing under favourable conditions great numbers of parasites and predators and releasing them whenever needed; and importing parasitoids, predators or disease producing organisms from a foreign country.



▲ **Fig. 80.1** *Parasite complex of major teak defoliators to illustrate the variety of parasitoids and their alternate hosts (after K.S.S. Nair)*

The basic principles to be considered in the selection of a natural enemy are the similarity of natural conditions, which would help in the establishment of the natural enemy in the new environment; the degree of host specificity and genetic races of a given natural enemy may also play an important role in view of the possibly better bio-ecological adaptations of particular races. It is also essential to develop a genetic strain of the parasites superior to the wild stock to have better effects.

Parasitoids and predators, which are to be deployed for efficient biological control must have the ability to outnumber the host by their high reproductive rate, greater percentage of females, short life cycle; and ability to locate the host. They should also be able to withstand competition. The tendency to exihibit multiple parasitism of hosts and susceptibility to hyperparasites are undesirable qualities and reduce the efficiency of the parasites. Multiple parasitism is a type of parasitism in which the same individual insect is inhabited simultaneously by the young of two or more different species of parasites. Super parasitism has to be distinguished from multiple parasitism. Super parasitism is the parasitism of an individual host by more larvae of a single parasitic species, while multiple parasitism is a simultaneous parasitisation of a host by two or more different species of primary parasites. When a parasitoid super parasitises a host it usually condemns its own progeny or at least individuals of its own species to death. Although super parasitism results in a wastage of progeny, the resulting individuals become weakened and cannot stand intraspecific competition. Multiple parasitism on the other hand is considered a tragedy because even that parasite which wins over interspecific competition is tired, weak, dwarfed, shows low fecundity and becomes totally undesirable in biological control work.

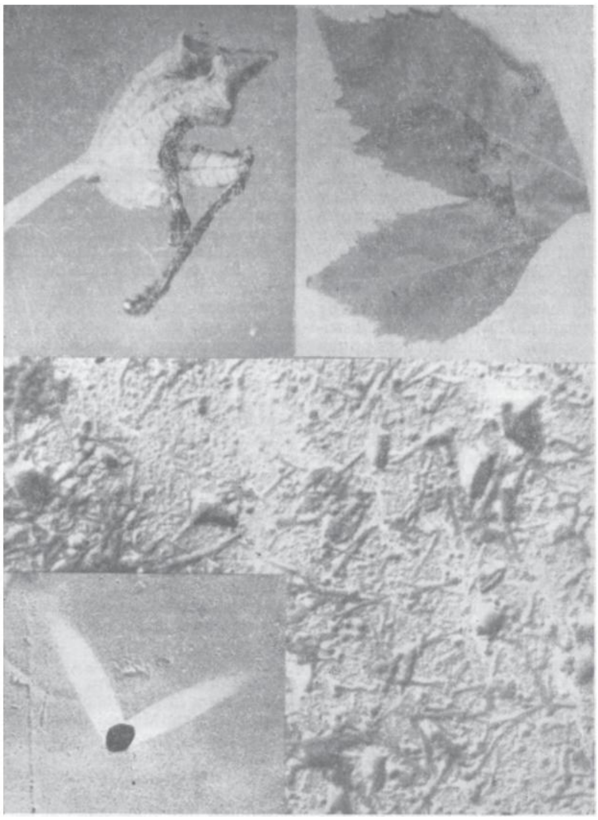
Very few primary parasites of any given insects are free from being parasitised by other parasites. The occurrence of higher parasitism in any (epi-parasitism) venture on biological control can only be considered as destructive, because a primary parasite imported for the purpose of introduction and establishment in the control of a pest may be overwhelmed by hyperparasites before it can succeed in controlling the pest.

Whether the host shows any defence reactions against the parasite should be an important consideration in any control programme. The most important is the problem of survival inside the body of another organism without arousing its immunological defence reactions. Normally the parasite is completely tolerated. The parasite develops and eventually destroys the host.

However, if the parasite lays its egg in an unnatural host, phagocytic haemocytes collect around the intruder in large numbers and encapsulate it. The parasite shrinks and turns black as melanin is deposited. Soon the parasite is sealed off and dies by asphyxiation. So encapsulation and melanisation are basic defence reactions against invading objects. Experiments have shown that repeated exposure of a host to the same parasite reduces their encapsulating ability. Again it was found that when a moth normally encapsulates 92 % of the singly laid eggs of an ichneumonid, and if super-parasitised by this species, the encapsulation rate drops to 3 %.

Another relatively recent aspect of biological control involves the application of insect's own pathogens for control. Like many animals, insects are also subject to many diseases—bacterial, fungal and viral. Many of these pathogens may be macerated or dried and distributed in water suspensions or as dry spores over large areas. *Bacillus thuringiensis* produces toxic protein crystals during spore formation. The active principle in the crystal is responsible for paralysis of the midgut within 5 to 20 minutes of imbibition of the sporulated bacillus, followed by paralysis of the body within one to seven hours. Lepidoptera and Coleoptera are most susceptible to this. Other bacteria are the deadly milky spore-producing bacteria *Bacillus lentimorbus* and *B. popillae*, which attack beetle grubs and caterpillars. Their action is to block the haemolymph and the whole blood becomes milky white. A new method for multiplying these spores in a liquid fermentation medium has been undertaken on an industrial scale. A talc-cum-limestone powder is chosen as the carrier of the commercially made milky dust. The dust is incorporated in the soil and the insects feeding on the roots consume the spores, get the infection and die.

Fungi were the first microorganisms recognised to produce diseases in insects, particularly the fungal diseases of silk worms produced by *Beauveria bassiana.* Subsequently, a more virulent fungus *Metarhizium anisopliae* was isolated from diseased grubs and even today used in the control of the coconut beetle. These fungal pathogens are known from all fungal groups Asco-, Basidio-, Phyco- and Deuteromycetes. Of the Phycomycetes, infections caused by Blastocladiales and Entomophthorales are very common. The Ascomycetes include a very common genus called *Cordyceps.* The Basidiomycetes are of little importance while the Fungi Imperfecti play a useful role in insect control. They infect their hosts not so much by ingestion but more by penetration through the integument, softening the hard chitin by releasing some enzymes. Once within the body cavity the fungus proliferates, invades all tissues and fills up the body cavity of the insect with thickly grown hyphae. Owing to heavy growth of the mycelium in the insect body, it becomes hard, stiff and mummified. Death is caused by the liberation of toxic substances—Mycotoxins. Death may also be caused by exhaustion or by mycosis or by paralysis or by asphyxiation through the plugging of tracheae.



▲ **Fig. 80.2** *Polyhedral virus of the tobacco caterpillar Spodoptera litura.Top left and right: The affected caterpillar; Bottom: The virus (courtesy : Dr. N. Ramakrishnan)*

About 250 virus infections have been recognised in about 175 insects. Of these, two are most outstanding, affecting most insects—the polyhedroses viruses (Fig. 80.2) and granuloses viruses. The polyhedroses viruses form polyhedra-shaped bodies containing the viruses in the infected tissues. Two types of polyhedra are recognised—the nuclear polyhedroses and cytoplasmic polyhedroses. The incubation period is 5 to 20 days and an infected larva stops feeding, becomes sluggish and dies. Shortly before and after the death, the integument becomes fragile and easily ruptures, emitting the liquified contents filled with disintegrating tissues and polyhedra. The granuloses viruses form small, granular, inclusion bodies called the capsules, each containing a virus particle. They are commonly used in the control of Lepidoptera and they attack the tracheae and blood cells.

The Sixth Commonwealth Entomological Conference held in London in 1954, recommended establishment of regional stations all over the world for work on biological control. Accordingly stations were started under Colombo Plan as a result of an agreement between the Governments of India and Canada and they were called Commonwealth Institutes of Biological Control. The Indian Station was started in 1957 at Bangalore. This station was taken over by the Indian Council of Agricultural Research and is presently known as the Project Directorate of Biological Control.

I. BIOLOGICAL CONTROL OF WEEDS

Biological control of weeds was started with the accidental introduction of the big *Orthezia insignis* which proved as a check against the proliferation of Lantana, an ornamental plant brought into Howaii. The weed, *Hypera perforatum*, a native of Europe, is known as St. John's Wort in Australia and New Zealand and as Klamath weed in the U.S.A. In California the weed was controlled by the introduced beetle, *Chrysomela gemellata*. Quite a few similar attempts on biological control of weeds in several countries have proved to be successful.

Insects should not be considered for noxious weed control, if they have been recorded as attacking plants of economic value. Insects recorded as attacking only the genus to which the noxious weed belongs or allies of it, having no economic value, should be subjects of future study.

1. Control of Cacti

One of the well known examples on the use of insects in the biological control of weeds was the fight against cacti in Australia. The prickly pear, *Opuntia inermis* got accidentally introduced into Australia by about 1840. The cactus spread so rapidly that in the course of next thirty years about twenty to twenty-four million hectares of arable land were rendered useless. The weed was attempted to be eradicated through the use of mechanical cutters, rollers and poisonous chemicals but without success. So, in 1925, the moth borer, *Cactoblastis cactorum* was introduced. The moth borer killed the plants by reducing them into papery structures.

The prickly pear *Opuntia vulgaris* Miller was suppressed in Central and North India by introduction of the mealy-bug *Dactylopius ceylonicus* (Green) from Brazil in 1795.

Experience of biological control of weeds in South India is another interesting story. The cactus *Opuntia dillenii* was wrongly introduced in 1780 in the place of *O. coccinellifera* for cultivation of the commercial cochineal insect *Dactylopius cacti* (L.), valued for its dye. The cactus got established. The cochineal insect was then obtained from Mexico. Since the insect was left with a wrong plant for its host, it did not thrive, allowing the cactus to spread rapidly and assume serious proportions as a noxious weed. Then the problem became one of eradication of the cactus. *Dactylopius opuntiae* Lichtenstein, a North American species, was introduced from Sri Lanka in 1926 and within two years the insect effected a striking control of *O. dillenii* and also of *O. elatior (O. nigricans)* to a lesser extent.

2. Control of Water-hyacinth *Eichhornia crassipes* (Pontederaceae)

Water-hyacinth is free-floating freshwater plant. It impedes flow of irrigation water, prevents free movement of boats; interferes with fishing and pisciculture, degrades the quality of water and increased silting and gradual drying of water bodies. It is also a threat to flooded rice fields where it reduces yield. In 1982 three exotic natural enemies viz. *Neochetina bruchi* Hustache, *N. eichhorniae* Warner (Curculionidae) and the mite *Orthogalumna terebrantis* Wallwork were introduced, and the former two have proved successful. *N. eichhorniae* adults are brownish-black and their body has grey and black scales. *N. bruchi* is reddish-black, broad-bodied, robust, densely clothed with agglutinate scales. Adults of both the weevils feed on the leaves of hyacinth and deposit their eggs below the epidermis of petioles and laminae. *N. bruchi* prefers basal ligules of outer leaves and *N. eichhorniae* prefers small, tender leaves. Whitish eggs of these species hatch in about a week.

The grubs are white or cream coloured with yellow or orange head. The grubs tunnel into the petioles and crown where they form pockets to feed extensively. The grubs leave characteristic black tunnels and the damage is often followed by invasion of pathogens, which weaken the plants further. Grubs pupate on live roots by cutting a lateral rootlet for making a spherical cocoon around themselves. Larval and pupal periods are completed in two months. The adults of *N. eichhorniae* and *N. bruchi* live for 142 and 134 days and lay 981 and 681 eggs, respectively. The weevil migrates up to 30 km.

These weevils can be used to control the weed. They can be reared in laboratories in large numbers under controlled conditions on the weeds and artificially inoculated on the weeds in natural conditions. Other management practices such as mechanical removal of the weed can also be followed simultaneously.

3. Control of Aquatic Weed *Salvinia molesta* (Salvinaceae)

This weed got introduced into India and first observed in the 1950s in Veli Lake in Thiruvananthapuram in Kerala. It became a serious weed since 1964. The weevil *Cyrtobagous salviniae* Calder and Sands, of Brazilian origin, was introduced from Australia in 1982 for the control of the aquatic fern *Salvinia molesta* and has now established in Kerala and Karnataka. Adults of the weevil feed on freshly emerged leaves and buds of *Salvinia.* They mate periodically throughout their life and the pre-oviposition period is 12.7 days with a range of 7.25 days. Adult males and females survive for up to 284 and 271 days respectively. Females oviposit up to 263rd day and a female lays 148 to 383 eggs. The eggs are laid mostly in the leaf keel and to a lesser extent in the root zone. Adults damage the leaf buds and the young terminal leaves; and feeding by larvae causes browning and decay of leaves. The capacity of the adults to live for as long as eight months combined with their ability to lay eggs continuously throughout their lives may be contributing to the effectiveness of the weevil.

The acridid grasshopper *Paulinia acuminata* (De Geer) introduced in 1974 got established but its potential as a bio-control agent has not been confirmed.

4. Control of Water-lettuce Pistia stratiotes L. (Araceae)

The water-lettuce has been noticed as a serious weed in Kerala. A noctuid caterpillar *Namagana pectinicoris* causes extensive damage to this weed and appears to be a potential bio-control agent.

5. Control of *Eupatorium adenophorum*

The exotic tephritid fly *Procecidochares utilis*, introduced from New Zealand in 1963 on *Eupatorium adenophorum* in the Nilgiris, caused galls on the plant but did not exercise effective control of the weed.

6. Control of *Chromalaena odorata* (Asgeraceae)

Chromalaena odorata, which is known as Siam weed, got introduced into Kolkata in the 1840s and has now spread throughout India. In Karnataka and Tamil Nadu it is a serious pest on plantation crops, forest areas, waste lands, and pastures. The leaf feeding moth *Pareuchaetes pseudoinsulata* Rego Barros (Arctiidae) was introduced in the 1980s in the Western Ghats. The seed feeding weevil *Apion brunneonigrum* (Apionidae) was also released in India but did not establish itself as a bio-control agent.

7. Control of *Parthenium hysterophorus* (Congress Weed)

The exotic beetle *Zygogramma bicolorata* Pallinter introduced from Mexico in 1983 for the control of the congress weed has been established in India.

8. Control of *Lantana camara* (Verbenaceae)

In the case of lantana, the introduced coccid, *Orthezia insignis*, in addition to its failure to effectively check the weed began to infest economic plants like citrus, coffee, cinchona and tomato; the seed fly *Ophiomyia lantanae* (Froggatt) introduced from Hawaii in 1921 did not establish itself in India. The Lantana bug *Telenomia scrupulosa* Stal. (Tingidae) was imported from Australia in 1941 and is suppressing the lantana weed successfully in some areas. In 1972 the chrysomelids *Octotoma scabripennis* Guerin Meneville and *Uroplata girardi* Pic. were introduced which got established.

II. BIOLOGICAL CONTROL OF INSECT PESTS IN INDIA

1. THE COTTONY CUSHION SCALE OR FLUTED SCALE *Icerya purchasi*

It is a scale insect, which is a polyphagous pest on a variety of fruit trees in Western countries. In Tamil Nadu it spread to an alarming degree on a variety of wild vegetation on the Nilgiris by about 1928. It had over 100 host plants but the only important crop affected was the wattle of commerical importance *Acacia decurrens*. The only successful way of controlling the pest is by its beetle predator *Rodolia cardinalis*. The beetles were initially got from California in May 1929, multiplied in the laboratory and released in infested areas. Another consignment of the beetles arrived from Egypt in 1930. By 1931, the incidence of the pest was practically reduced to negligible limits. A severe outbreak on Acacia was again reported from Kodaikanal in 1942 and subsequently from the Nilgiris also. Intensive work was taken up in May 1943 and continued till 1945. The activity later merged into an all-India coordinated scheme under the joint auspices of the then Madras Government (Tamil Nadu) and the Government of India.

Attempts made to introduce the exotic fly parasite *Cryptochaetum iceryae* against the pest were not successful. Similarly *Rodolia nezara* from Kerala, *R. amabilis* and *R. fumida* from Mysore and *R. breviscula* from Coorg were tried at Fernhill (Nilgiris) against the pest but did not succeed.

2. THE COCONUT BLACK-HEADED CATERPILLAR *Opisina arenosella*

It is one of the most serious pests of the coconut palm. The search for natural enemies and the attempts to employ them for biological control succeeded by 1926. Of the many natural enemies observed, the most important have been *Goniozus nephantidis* (Bethylidae) parasitising the grown-up caterpillars and *Trichospilus pupivora* (Eulophidae), a pupal parasitoid. These were bred in the laboratory and were released. To a lesser degree *Elasmus nephantidis* and *Bracon brevicornis* also proved to be amenable to mass breeding. These parasitoids are multiplied now in large numbers in the parasite breeding stations at several places in the country and liberated into the pest-infested areas for effective control.

An ichneumonid parasitoid *Eriborus trochanteratus* obtained from Sri Lanka was multiplied and released for the control of the pest around Coimbatore. The larval and pre-pupal parasitoids *Goniozus nephantidis, Bracon brevicornis, Apanteles taragamae* and *Elasmus nephantidis*, and the pupal parasitoids *Trichospilus pupivora*, *Tetrastichus israeli, Brachymeria nephantidis, B. lasus. B. nosatoi* and *Xanthopimpla punctata* are being mass multiplied in bio-control laboratories of Kerala for periodical releases.

(a) *Goniozus nephantidis* is shiny black in colour and ant-like in appearance. It is a larval parasite and attacks only *Opisina arenosella* caterpillars. The adults of the parasitoids, which emerge from the cocoons, are kept in 15 × 2.5 cm tubes. For feeding drops of sugar solution (1 part of sugar in 10 parts of water) are kept on a small paper slip dipped in wax; and the same changed every day. Mating takes place within a day or two of emergence. The mated females are separated and each parasite is taken in a small tube of 7.5 × 2.5 cm. Grown-up caterpillars are introduced into these tubes at the rate of one caterpillar per tube. The parasitoid paralyses the caterpillar and starts laying eggs. The elongate eggs are firmly glued on the sides of the host and 8 to 20 eggs are laid on a caterpillar. Grubs hatch in about 36 hours and begin to feed on the body fluid of their host. Larval stage lasts four to six days and pupal stage four days. When fully fed, the grubs detach themselves from the dead caterpillar and spin loose, flimsy cocoons of silk. The total life cycle varies from 11 to 16 days.

(b) *Trichospilus pupivora* is a tiny yellowish-brown wasp, which attacks the pupae of *Opisina.* In the laboratory it can be freely bred on pupae of various species of Lepidoptera such as *Ariadne merione merione, Conogethes punctiferalis, Plusia* sp., *Spodoptera litura*, *Syllepte derogata*, etc. Mating takes place inside the parasitised pupa even before emergence and hence the parasites are ready for egg-laying. Only fresh pupae of the host are taken in tubes of 7.5 × 2.5 cm and the parasites allowed inside at the rate of about 20 per tube. The minute eggs hatch in a day, and the grubs become full grown in five to six days and form naked pupae. The pupal period is about 16 to 17 days on an average. It cannot survive the summer conditions and has to be propagated every year.

The parasitoids are taken to the top of the trees and released at the rate of about 10 parasitoids per tree in a few places in a garden.

(c) *Spoggossia bezziana*, the exotic tachinid fly parasitoid, from the then Commonwealth Institute of Biological Control, Bangalore, was mass multiplied and liberated into the coconut gardens (Fig. 80.3) around Coimbatore. The attempts were not continued.

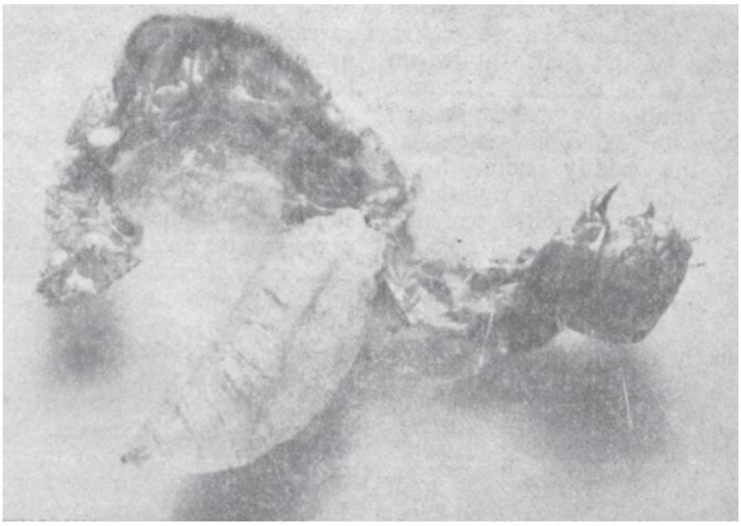


Fig. 80.3 *The tachinid Spoggossia bezziana emerging from the caterpillar of Opisina arenosella (Courtesy: Dr. V. P. Rao)*

3. SUGARCANE BORER *Chilo infuscatellus*

The eggs of *Corcyra cephalonica* are collected and they are used for multiplication of the parasitoid. For this purpose the moths collected are put inside an inverted big-sized funnel having its bottom closed with a wire-mesh. This funnel is kept on a piece of white cardboard overnight. On the next day morning the eggs deposited on the cardboard are collected. The eggs are sprinkled on a wet paper and then dried. These cards are kept inside a tube and the *Trichogramma chilonis* parasitoids are introduced. In two to three days the eggs get parasitised and the parasitised eggs turn dark. The parasitised egg cards are sent to the respective places for hanging them in the sugarcane fields. The parasites come out of the eggs and attack the eggs of *Chilo infuscatellus.* Stapling 100 egg-cards (5×2.5 cm) with seven-day old eggs of *Corcyra* parasitised by *T. chilonis* to the undersides of leaves of sugarcane from July to October at 10-day interval is suggested. Normally 10 to 12 releases at the rate of 50,000 parasitised eggs/ha is recommended.

4. THE INTERNODE BORER *Chilo sacchariphagus indicus*

Inundative release of *Trichogramma chilonis* at 2,50,000 parasitoids/ha in phases during the different stages of crop growth i.e. 25000 parasitoids/ha per release during fourth and ninth months and 50,000 parasitoids/ha per release during fifth, sixth, seventh and eighth months is recommended for the control of internode borer in Tamil Nadu.

5. THE TOP BORER OF SUGARCANE *Scirpophaga excerptalis*

The ichneumonid parasitoid *Gambroides javensis* has been found promising in the control of the top borer on sugarcane in Pugalur area. Inoculative release of the parasitoid at the rate of 125 females/ha in fields showing more than 10% top borer infestation is recommended.

6. THE STALK BORER *Chilo auricilius*

The cuban fly *Lixophaga diatreae* imported from Taiwan in 1962 indicated promising results in the control of the stalk borer *Chilo auricilius.* It has been found that in Uttar Pradesh, the fly has been able to survive the North Indian winter. Another fly *Diatraeophaga striatalis* (tachinid) received from Malagasy Republic in 1965 was released in Tamil Nadu. Sequential release of 125 gravid females of the tachinid parasitoid *Sturmiopsis inferens* per ha from 30^{th} to 50^{th} day of planting is suggested.

7. THE SUGARCANE SCALE *Melanaspis glomerata*

Release of about 1500 beetles of *Pharoscymnus horni* or *Chilocorus nigritus* per hectare at the first appearance of the scale insect is suggested. *Sticholotis madagassa* Weise (Coccinellidae) and *Anabrolepis mayurai* Subba Rao have been found suitable for suppression of the scale.

8. THE SUGARCANE PYRILLA *Pyrilla perpusilla*

Effective nymphal and adult parasitoid *Epiricania melanoleuca* has also been successfully colonised in Gujarat, Madhya Pradesh, Maharashtra, Rajasthan, Karnataka and West Bengal besides other areas in the control of sugaracane pyrilla. Release of 8,000 to 10,000 cocoons or 8,00,000 to 10,00,000 eggs of *E. leuconella* per ha is recommended. Leaf bits bearing two to three egg masses or five to seven cocoons can be stapled to the underside of sugarcane leaf at several places in the field.

9. THE APPLE WOOLLY APHIS *Eriosoma lanigera*.

This is a serious pest of the apples and the recognised method of control is by systematic colonisation of its specific parasite *Aphelinus mali.* Consignments of the parasite were obtained from Punjab in 1940 and liberated in the Pomological Station, Coonoor. The work was intensified from 1944 onwards and appreciable control has been effected. Heavy predation by *Coccinella septempunctata* and *Adonia variegata* also keeps the pest under control.

10. THE APPLE SAN JOSE SCALE *Quadraspidiotus perniciosus*

Russian, American and Chinese strains of *Encarsia perniciosi, Aphytis diaspidis* and *A. proclia* group effectively suppressed this pest on apple. *Chilocorus bijugas, Pharoscymnus flexibilis* and *Cybocephalus* sp. also play an important role in the population suppression of this pest.

11. THE APPLE CODLING MOTH *Cydia pomonella*

Inundative releases of *Trichogramma cocoeciae* and *T. embryophagum* have been found promising against apple codling moth in Ladakh.

12. COTTON BOLLWORMS

Weekly releases of *Trichogramma* at 25,000 per hectare from flowering season till the ripening of the bolls showed a progressive decline in infestation of the bollworm *Helicoverpa armigera* and pink bollworm *Pectinophora gossypiella* on cotton. The exotic parasitoid *Bracon kirckpatricki* has suppressed the cotton bollworms in Karnataka, Haryana, Punjab and Gujarat. It was also found parasitising hibernating larvae of pink bollworm in the north. *Chelonus blackburni* has established in north as well as in the south. Utilising the parasitoids *Trichogramma brasiliensis, T. chilonis, C. blackburni* and *B. kirckpatricki*, the predator *Chrysopa scelestes* and the NPV of *Helicoverpa armigera* the cotton bollworm complex can be effectively suppressed.

13. THE RICE STEM BORER *Scirpophaga incertulas*

The rice stem borer incidence is reduced by periodical release of the parasitoid *Trichogramma chilonis* at 40,000-50,000 parasitoids/ha.

14. THE RICE LEAF FOLDER *Cnaphalocrocis medinalis*

Periodical release of *Trichogramma australicum* at 50,000 parasitoids/ha has given effective control.

15. THE BROWN PLANTHOPPER (BPH) *Nilaparvata lugens*

Release of the mirid bug *Cyrtorhinus lividipennis* at 100 bugs or 50-75 egggs/m^2 at 10 days interval checked the build up of BPH population to some extent.

16. THE TOBACCO CATERPILLAR *Spodoptera litura*

Since 1974 the egg parasitoid *Telenomus remus* (Scelionidae), obtained through the Commonwealth Institute of Biological Control, Bangalore, was mass multiplied and released in Rajahmundry (Andhra Pradesh) for the control of the tobacco caterpillar.

17. THE CITRUS BLACKFLY (CBF) *Aleurocanthus nagpurensis*

There was an outbreak of the CBF in the Vidarbha region of Maharashtra state and the species was established as *Aleurocanthus nagpurensis*, though earlier it was variously identified as *A. woglumi* and *A. husaini*. This species has been effectively kept under check by the parasitoid *Encarsia orangae*. The methods for mass rearing of the pest and the parasitoid were developed at Nagpur University and releases made during 1986 and 1987 in the citrus orchards at Nagpur University brought the pest under check by 85-90% within one year. This appears to be a potential bio-control agent for the control of *A. nagpurensis*.

18. THE SUBABUL PSYLLID *Heteropsylla cubana*

The exotic coccinellid *Curinus coerulens*, a shiny bluish-black beetle was introduced into India from Thailand in October 1988 for the control of the psyllid, which got entry into India in February 1988.

19. THE AUSTRALIAN LADYBIRD BEETLE *Cryptolaemus montrouzieri* (Coccinellidae)

This was imported into India in 1898 from the USA. Since then it was seen occurring in Taliparamba in 1930, in Bangalore in 1940 on mealy bugs and in 1951 on trunks of Araucaria pines, in Anamalai in 1931 on guava scale and in Coimbatore in 1942 on guava scale and in 1944 on brinjal. During the survey of the Cactus on the Nilgiris it was found at Anikorai that the cochineal *Dactylopius tomentosus* on the prickly pear *(Opuntia dillenii)* was being preyed upon by the adults and larvae of this beetle. Experiments conducted on the mass multiplication and releasing of the predator at Coimbatore for controlling mealy-bugs like *Coccidohystrix insolitus* on brinjal, *Chloropulvinaria psidii* on sapota and guava, *Pseudococcus corymbatus* on citrus, *Pulvinaria maxima* on neem, etc. gave some control. However, the relief was only partial due to depredatory activity of the ants, which proved inimical to the predatory grubs and adults. It has also to be replenished every year. Presently it is used for the control of mealy-bug on grapevine.

The other common predaceous insects in South India include, the coccinellid beetles *Cheilomenes sexmaculatus* on aphids on a variety of crops and *Chilocorus nigritus* predominantly on scale insects attacking coconut, betelvine, neem, tapioca, etc.

BIOLOGICAL CONTROL THROUGH PREDATORY VERTEBRATES

Among the vertebrates, the birds are in fact the most effective bio-control agents as a proportion of food of most birds is made up of insects. Yet, there have been no spectacular cases of transportation of birds from one country to another to combat insects. In South India, occasionally ducks are allowed into paddy fields for feeding on the striped bug Tetroda histeroides. A flock of 1000 ducks can clear a badly infested patch of about 5 ha in the course of two or three days, each bird accounting for about 500 bugs in a day. However, some birds play the role of bio-control agents of insect pests of different kinds such as caterpillars, grasshoppers, white grubs, etc. The important insectivorous bird species are: the mynah *(Acridotheres tristis)*, the king crow *(Dicrurus ater)*, the wood pecker *(Brachypternus auranticus)*, the owl *(Athene brama)*, the house crow *(Corvus splendens)*, the common weaver bird *(Ploceus phillipinus)*, the house sparrow *(Passer domesticus)*, the common bee eater *(Merops orientalis)*, the rose-ringed parakeet *(Psittacula krameri)*, the black rock pigeon *(Columba livio)*, the bulbul, the tailor bird, the hoopoes, the fly catcher, fowls, turkeys, etc.

BIOLOGICAL CONTROL THROUGH NEMATODES

Nematodes especially rhabditids are found to have a symbiotic relationship with the bacteria, forming a disease complex. The best known disease complex was discovered by Dutky and Hough in 1955 in the caterpillars of the codling moth, *Cydia pomonella* (L.). The complex was known as DD-136 though the nematode itself was often called so. The nematode involved is *Steinernema feltiae* (*Neoaplectana carpocapsae* Weiser) and the bacterium *Xenorhabdus nematophilus.* The nematode serves as a vector for the bacterium, which produces speticemia in the insect body. When the nematode enters the insect body the bacteria are released and they multiply. The nematode ingests both the dead host tissue and the bacteria. The bacteria are retained in nematode intestine, as the latter does not feed during its free-living existence. When such bacteria-carrying nematodes invade fresh insect hosts they are killed likewise. Though even a few nematodes can kill the host, sufficient number of them should invade the host to ensure reproduction through production of each sex of nematode. The dead body of the insect remains intact with putrefaction for more than three weeks, perhaps due to production of certain antibiotic by bacteria that inhibits the growth of other micro-organisms. Both nematode and bacteria can be cultured separately. A wide range of insect species is susceptible to the disease complex. In India it was tested against rice and sugarcane borers and codling moth. It was found promising against larvae of *Helicoverpa armigera.*

The mermithid *Ovomermis albicans* is parasitic on larvae of *H. armigera* and *Spodoptera litura* and need to be evaluated.

BIOLOGICAL CONTROL THROUGH INSECT DISEASES

Employment of micro-organisms capable of causing diseases in insects is another means of fighting crop pests, i.e. number of fungi, bacteria, viruses and protozoa are able to cause diseases in insects.

(a) Bacteria

Dutky in 1937 found an oval-shaped bacterium containing spindle shaped retractile bodies associated with a species of *Neoaplectana* occurring in the larvae of Japanese beetle *Popillia japonica* Newman. He showed that the bacteria could be transferred by the nematodes from one larva to another. The control of this beetle by the nematode-transmitted bacterium *Bacillus popillae* provided an outstanding example of practical utilisation of an insect disease in the control of insects.

Out of about 100, pathogenic bacteria described from insect *Bacillus thuringiensis* Berliner has been found to be the most useful one. It was isolated by Berliner in 1915 in Germany from the diseased larvae of the Mediterranean flour moth, *Ephestia kuhniella.* It is a spore-forming crystalliferous bacterium. Since 1946 it has been tried in insect control and has been found to b capable of killing many lepidopterous larvae. The infection occurs through ingestion and the bacterium develops in the intestinal tract of its host later passing on to it haemocoel causing septicemia. *Bacillus thuringiensis* and related genera are highly pathogenic to those lepidopterous larvae, which have an alkaline pH of the gut but are non-pathogenic to those having slightly alkaline or neutral gut pH as in the larva of noctuids and sawflies. In this respect action of *B. thuringiensis* toxin is very much similar to that of the phytogenous insecticide, rotenone, for ingestion of small quantities of rotenone can bring about rapid death in silk worm larvae with a high gut pH whereas even large quantities will not have any adverse effect and the ingested rotenone is voided in faeces in *Spodoptera* catepillars with a low gut pH. In susceptible insects the crystalline toxin of the bacterium makes the gut wall permeable to spores and bacteria and as a result the latter pass into the haemocoel and cause septicemia. In infected insects the blood pH is usually lowered. But in most susceptible insects, which have a highly alkaline gut contents, because the gut wall is made highly permeable by the toxin, the alkaline fluids in the gut permeate into the haemocoel resulting in an increase in blood pH. In several countries like U.S.A., France, Germany, Czechoslovakia and U.S.S.R. this bacterium is produced in large quantities and its commercial preparations are marketed. Since the main activity of *B. thuringiensis* against insects is a result of toxins, which act as stomach poison, the bacterium has to be applied regularly and in correct quantities as in the case of chemical insecticides without depending upon its natural spread. The bacterial spore dust is prepared by growing bacteria over large areas of nutrient agar. The bacterial spores are washed off with a little quantity of water, added on to one of the usual dust carriers of chemical insecticides especially the talc, dried in an oven and pulverised to a fine powder. The formulation is so standardised that a gram of concentrated spore-dust suspension has 100 million spores. It can be applied as a dust or water suspension spray against a variety of lepidopterous and coleopterous larvae. It is non-toxic to man, other vertebrates and beneficial insects. It leaves no residue in plants. It is compatible with a number of chemical insecticides like carbaryl, demeton, malathion and parathion. The microbial insecticide is to be applied under proper weather conditions, especially temperature and it lacks residual action.

Another bacterium of recent application in biological control of insects is the red pigmented bacterium, *Serratia marcescens* Bizio. It belongs to a non-spore-forming type and has been found to be useful against a number of lepidopterous insects. The bacterium *Coccobacillus acridiorum* has been used against grasshoppers in part of Africa.

Bacteria based Biopesticides in India

1. Agricultural Pests Control

Bacillus thuringiensis var. *kurstaki* is available as a water dispersible powder formulation. It is selectively toxic to the lepidopterous larvae of various crops and has no harmful effect on human, warm blooded animals, wild life like birds, fishes frogs, honey bees and other beneficial insects. The product is based on a highly potent strain of *B. t. var. kurstaki*, serotype H 3a, 3b isolated in 1962. It is toxic to caterpillars such as *Helicoverpa, Plutella, Spodoptera, Earias, Spilarctia, Amsacta, Agrotis, Lymantria,* etc. Viable spore count in the commercial formulation is around 90-102 billion spores/g. Early instar larvae are most susceptible and later instars show little effect due to cessation of feeding by caterpillars. It exhibits quick knockdown activity within few hours of application and kills within two to three days of application. It is recommended at 0.5 to 1.0 kg/ha. This product has been registered for use in India and is now being produced, formulated and marketed.

Bacillus popillae occurs naturally in India and when applied as spores, has been found effective under field conditions against the white grubs *Holotrichia consanguinea*, *H. serrata* and *Leucopholis lepidophora*.

2. Public Health Pests Control

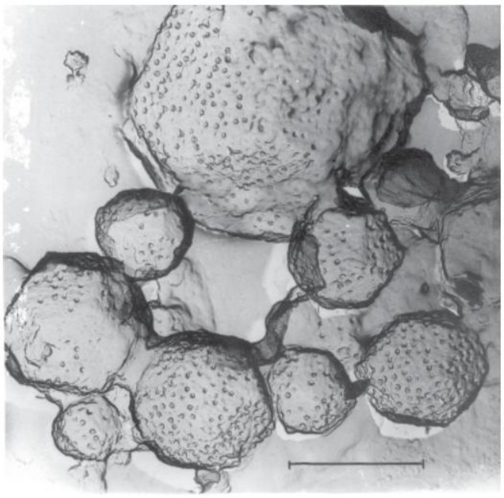
Bacillus thuringiens is var. *israelensis*, Serotype H-14, strain 164, is available as a water dispersible powder formulation. It is highly effective against first three larval instars of various mosquito species of the genera *Aedes, Culex, Anopheles, Mansonia,* etc., which are vectors of malaria, filarial, encephalitis and dengue fever in addition to being of nuisance. It is applied at 1.0-5.0 kg/ha, at 0.5 g/sq. m. water surface, as 0.5% suspension, by knap-sack sprayer at two to six weekly intervals. It results in sharp and continuous decline of *Anopheles* and *Culex* larval populations (90-97%) in various habitats and different ecological sites including drains, water streams, sewage tanks, water coolers, cooling towers, fountains, construction sites, rice fields, septic tanks, ditches, pools, marshy ponds, etc. It is used by NMEP (National Malaria Eradication Programme), Municipal Corporations in Delhi, West Bengal, Maharashtra, Tamil Nadu and Kerala, and also by World Health Organisation (WHO) in Maldives. This product has been registered for use in India.

Bacillus sphaericus has also been found to be effective against the larvae of the mosquitoes mentioned above.

(b) Viruses

More than 250 insect viruses have been described as capable of causing diseases in insects. The jaundice or *grasseri* of silkworm, paralysis of honey bees and polyhedrosis of caterpillars are some examples of viral diseases in insects. Infection in insects by certain viruses is distinguishable by the presence of characteristic cell inclusions and that by certain others by the absence of any inclusions. The inclusion may be polyhedral, polymorphic, or granular.

The polyhedrosis virus may be called as nuclear or cytoplasmic, according to the site of its multiplication. The nuclear polyhedral virus, Borrelinavirus, is rod shaped and multiplies in body wall tracheae, fat bodies and blood cells. The polyhedra are seen in nuclei of cells. The cytoplasmic polyhedral viruses multiply in cell cytoplasm of the gut and the polyhedra are never seen in cell nuclei. In the case of nuclear polyhedrosis viruses, they invade the cells and multiply and the multiplied viruses invade uninfected cells. Polyhedra are formed in the cell nuclei. The polyhedra and the host nuclei enlarge in size and the infected cells are ultimately destroyed releasing the polyhedra into the body cavity. A few hours after the larvae die of polyhedral diseases, their internal tissues become liquefied, containing large number of polyhedral bodies in the liquid. An individual polyhedra is about 0.5 to 15 microns in diameter, never sphere-like and is usually refractive and crystal-like with many faces; it is made of concentric layers like an onion. Nuclear polyhedrosis viruses have been observed to affect about 200 species of insects, mostly of Lepidoptera and to a less extent of Hymenoptera and Diptera. The viruses are carried from one generation to the next, through transovum infection. In India nuclear polyhedroses of *Corcyra cephalonica, Pericallia ricini, Amsacta albistriga, Spodoptera litura* and *Helicoverpa armigera*, cytoplasmic polyhedrosis of *Helicoverpa armigera* (Fig. 80.4) granuloses of *Pericallia ricini, Chilo infuscatellus* and *Cnaphalocrocis medi-nalis* have been observed. Insect viruses have the greatest potential for field use because of their specificity and effectiveness against



▲ **Fig. 80.4** *Electron micrograph of carbon replicas of cytoplasmic polyhedra of Helicoverpa armigera showing pits where virions have been etched. Line = 1.01 μ (Courtesy: Dr. R.J. Rabindra)* many important crop pests. The nuclear polyhedroses and granuloses are most lethal and also the most promising viral insecticides. Though non-inclusion viruses also quite virulent, their environmental presistence is questionable. Polyhedroses of *Chilo, Carpocapsa, Estigmene, Helicoverpa, Laphygma, Pieris, Plusia, Spodoptera and Trichoplusia* are some of the commercial viral insecticides available in other countries.

Baculoviruses in Pest Control in India

The baculovirus group of viruses is the most predominant among the insect viruses and is apparently confined to invertebrates particularly the insect orders Lepidoptera, Hymenoptera, Diptera and Coleoptera. These viruses are structurally complex with double stranded DNA having rod-shaped or bacilli-form virions. In the majority of the cases virions are occluded within a crystalline protein coat to make up a virus inclusion body. These inclusion bodies are polyhedral in shape in the case of nuclear polyhedrosis viruses (NPVs) or form capsules as in case of granulosis viruses (GVs). No inclusion bodies are formed in some baculoviruses such as *Oryctes* virus wherein nucleocapsid is always enveloped singly within the virion. In India among 35 insect viruses recorded, the most important are the NPVs of *Helicoverpa armigera, Spodoptera litura, Spilarctia obliqua, Achaea janata* and *Amsacta albistriga* and GVs of *A. janata, S. litura, H. armigera, and Chilo infuscatellus.* The granulosis virus infecting sugarcane shoot borer is found widely distributed in Tamil Nadu and Pondicherry. Four sprays of the virus at 10^{-6} – 10^{-8} inclusion bodies/ml applied at fortnightly interval commencing from the 30th day of crop stage have given good control of the pest. However, large scale production of the virus is rather difficult in the absence of an alternative host and there are also limitations in mass rearing of the shoot borer.

A number of companies, Agricultural Universities and state departments of agriculture produce NPVs of *H. armigera, S. litura* and *Amsacta albistriga* and supply them commercially to the farmers for pest control. The product Biovirus marketed in India is a moisture absorbing powder formulation of *H. armigera* NPV containing 7×10^{-9} PIB/g having a storage stability for two years at 40°C. It is applied at 300-500 g/ha, two to three times at 10-15 day interval.

Baculovirus oryctos has been found to successfully control the coconut beetle *Oryctes rhinoceros* under field conditions in the Lakadive Islands.

(c) Fungi

Out of about 530 entomopathogenic fungi described under all classes, viz, Phycomycetes, Ascomycetes, Basidiomycetes and Deuteromycetes, about fifty species of the genera *Entomophthora* (Phycomycetes), *Aspergillus, Beauveria, Isaria, Metarhizium* and *Spicaria*

(Deuteromycetes) are more commonly found in insects. They attack usually dipteran insects followed by Hemiptera, Lepidoptera and Coleoptera. In all cases the adults are more commonly affected than the larvae. *Entomophthora grylli* on grasshoppers, *E. sphaerosperma* on cabbage butterfly and leaf hoppers, and *Metarhizium anisopliae* on sugarcane pyrilla and grubs of rhinoceros beetle are some common examples of fungal diseases in insects. In South India, *Cephalosporium lecanii, Entomophthora lecanii* and *E. fresnii* have been noticed to keep in check the coffee green scale *Coccus viridis. Spicaria* sp.and *Cladosporium* sp. on the castor whitefly *Trialeurodes ricini, Aspergillus flavus,* on *Pelopidas mathias mathias* and *Henosepilachna vigintioctopunctata*, and *Cladosporium* sp. on *Icerya purchasi* in the Nilgiris are other fungi noticed. *Beauveria bassiana* infects castor semilooper and *Isaria stellata* infects *Amritodus atkinsoni* and *Idioscopus clypealis* in Mysore.

Beauveria brongniartii is the most abundant white grub pathogen and infects members of Rutelinae, Melolonthinae, and Cetoniinae and deserves consideration. *B. bassiana* infects *Holotrichia serrata. Paecilomyces farinosa* infects *Eligma narcissus. P. fumasoroseus* naturally infects adults of the whitefly *Bemisia tabaci.*

Most of the entomopathogenic fungi are facultative parasites. The infective spore on germination penetrates the integument with mechanical pressure or enzymatic action. Hyphae can also initiate infection. They produce toxins, which act as poisons for the insects. The toxins produced by *B. bassiana* are Beauvericin, Beauverolides and Bassinolide and by *Metarhizium* are Destruxins A,B,C.D,E,F.

The fungi that are commercially produced and used in the biological control of insects are *Beauveria bassiana* and *Metarhizium anisopliae* by small scale units in the country.

(d) Protozoa

The result of parasitism by protozoa on insects is mainly debilitative, predisposing them to death by other causes. About 210 pathogenic protozoa have been described in insects. They include such well-known species as *Nosema bombycis* on silkworms, *Malpighamoeba mellificae* on honey bees in Europe and *M. locustae* on grasshoppers. The protozoan *Farinocystis tribolii* has been noticed to infect *Tribolium castaneum* in India. The role of protozoa as microbial agents in artificial control is limited because of the difficulties in their mass production for field release. The various protozoan pathogens propagated in other countries for use in biological control include *Malamoeba locustae, Mattesia grandis, Nosema bombycis, N. lymantriae* and *Perezia pyraustae. P. pyraustae* has been used against the European corn borer.

BIOLOGICAL CONTROL OF VECTORS AFFECTING MAN

(i) *Domiciliary Cockroaches* In India augmentative releases of the indigenous parasitoid *Tetrastichus hagenowii* (Ratz.) (Eulophidae) have given promising results in the control of

Periplaneta americana. The cockroach *Neostylopyga rhombifolia* (Stoll.), restricted to thatched huts, is parasitised by *Anastatus umae* Boucek (Eupelmidae). *Evania appendigaster* (L.) (Evaniidae) is parasitic in the oothecae of *Periplaneta americana, P. brunnea* Burmeister, *P. australasiae* (F.) and *N. rhombifolia*, but is only of minor importance.

(ii) *Housefly* Five species of parasitoids viz., *Spalangia cameroni* (Perkins), *S. endius* Walker, *S. nigra* Latreille, *S. nigroaenea* Curtis and *Pachycrepoideus vindemmiae* Rondani (Pteroma-lidae) are parasitic on puparia in pig manure. In addition, *Dirhinus pachycerus* Masi (Chalicididae) parasitises the puparia in poultry manure. *S. cameroni, S. endius* and *S. nigroaenea* pararistise the puparia in cattle manure.

(iii) *Mosquitoes* Three species of exotic larvivorous fish *Carassius auratus* (L.), *Gambusia affinis* (Baird and Girard) and *Poecilia reticulata* Peters have been successfully colonised in many parts of India to destroy mosquito larvae in wells, ponds and other confined water bodies.

ADVANTAGES OF BIOLOGICAL CONTROL

1. The control over the insect is exercised in a wide area. The co-operative effort of the farmers of a locality is not necessary, as will be required in large scale chemical control operations like aerial spraying.
2. Though the initial cost in procuring the biological agents and initiating the project may be high, in the long run it becomes cheaper as the recurring expenditure will be very little later on.
3. The pest is hunted out even in its wild haunts inaccessible for other methods of control and thus a complete control over a large area is possible.
4. The biological agent will survive as long as the pest is prevalent and, therefore, the control effected may last over a long period.
5. When successfully established the biological agent can perpetuate itself and, therefore, after a few years of field release there may not be any necessity to propagate it further.

Limitations of Biological Control

1. It is a slow process and takes a long time. An imported natural enemy, if it does not establish itself within three years of careful release under optimum conditions, may not be an useful biological agent Further, the farmer does not like to wait for the natural enemy to do its job and he always expects quick results of control.

2. The work of the natural enemy cannot be restricted to particular crops or areas.
3. If alternative hosts of the natural enemy are present in abundance, the control exercised over a specific pest may not be to the desired extent.
4. If certain seasons of a year are unfavourable for the normal development of a natural enemy, replenishment will become necessary every year.
5. The effect and progress of the work of the natural enemy will be affected considerably if it is attacked by hyper parasites in the locality.
6. Use of chemical pesticides adversely affects the population level of natural enemies.

◆ Chapter 81

Insect-Plant Interactions

The adaptive spectrum of insects to their host plants involves behavioural as well as metabolic changes, which reflect the overwhelming diversity in insect-plant interactions. These changes enable insects to cope with the physical and chemical defence systems in plants to which phytophagous insects have long been adapted during evolution. Detoxification and chemosensory mechanisms enable these insects to respond differently to different chemical compounds so that they are able to identify the plants to which they are chemically adapted. For purposes of defence, plants have been known to extend a portion of their metabolic energy and nutrients on various host selection devices. This process of co-evolution or reciprocal adaptation has come to be recognised, although the pattern of feeding diversity eludes convincing explanation. Phytophagous insects derive adequate nourishment from most plant tissues, and different species have different nutritional requirements, so that varying degrees of feeding discrimination are evident. The degree to which a plant species is immune to the attack of insects in general, is indicative of the defence strategies it has evolved, as well as the evolved abilities of insects to overcome the defences. While this is what has been termed 'the evolutionary arms race', there has been an increasing trend to consider insect-plant interactions as involving an integration of numerous complex chemical and non-chemical factors. In other words insect-plant interaction can be better understood only when approached as a holistic phenomenon in community ecology. For instance, the adaptive flexibility of insects to respond to ecological selection pressures is as important as the chemical composition of food plants. A knowledge of plant chemistry will ultimately make it possible to better understand insect community structures because of its influence on population, energy flow, and nutrient cycles. Issues such as the role of water, nitrogen, and phenolics in insect feeding, physico-chemical and biophysical aspects of interaction of natural toxins enable an understanding of the sequestration and detoxification mechanisms as well as mechanisms of plant resistance; these have to be examined in depth in relation to the feeding and reproductive processes in insects. The physiology and behaviour of as many phytophagous insects as possible need to be studied in order to provide a more convincing picture of the spectrum of interaction involved, since the presence of specific chemicals may offer protection from one insect pest, but may increase risk of invasion by others.

WATER AND NITROGEN

The role of water as a stimulus in eliciting an orientational response of phytophagous insects towards the host plant has often been overlooked. Insects such as the leaf miners and gall insects are protected from desiccation by their habitats and rapidly die from loss of water when removed from their immediate surroundings. In the absence of plant odour the stimulus provided by a thin layer of moist air associated with leaf surface could evoke a positive response.

Several problems have emerged in recent years regarding the leaf surface, from surface trichomes to cuticular lipids. The role of cuticular lipids in insect-water balance and reaction to water stress appears to be related to the lipid composition of the host plant. The increasing realisation that the regulation of water in insects involves an inter-disciplinary approach embracing biophysics, ecology and cell physiology, has opened up new areas of useful research. Regulation of water balance is also one of the ways to successfully adapt phytophagous insects to a wide range of habitats.

Plants are also known to defend themselves through lower levels of nitrogen, or low water/nitrogen ratio, and several plants are known to store nitrogen as non-protein amino acids so that there is a combined operation of reduction in available nitrogen with chemical defences. Increased plant nitrogen increases insect damage and plants generally exhibit seasonal patterns in the levels of nitrogen in leaves, fruits, stems and various tissues. The survival and reproduction of insects are influenced by both the quality and quantity of nitrogen. In addition, the ability of insects to ingest, digest and convert plant nitrogen is also important, besides the utilisation of amino acids. While insects have high protein content, plants contain predominantly carbohydrates and thus nitrogen content in protein is often a critical component for insects.

Water influences insect growth in the immature stages. Foliage water content varies with plant growth form. Young leaves and shoots contain a high percentage of water compared to the mature parts. Thus the age of a leaf and consequent availability of various chemicals play a vital role in host selection. Obtaining an adequate intake of protein and amino acids becomes more complicated due to variation in leaf nitrogen content as well as water content in relation to seasonal changes.

PHYSICAL AND CHEMICAL DEFENCE SYSTEMS IN PLANTS

Many phytophagous insects have developed trophic strategies to exploit plant structures or orientation mechanisms so that the average size of the species guild is an indicator of the adaptive radiation, which may occur on the same plant species, where different regions are exploited by very closely related species. As related plant species usually offer similarities with regard to structural features and chemical compounds, such species require less utilisation of biological adaptation and chemosensory mechanisms than when an entirely unrelated plant is colonised by an insect. Two theories are currently in vogue: *Evolutionary opportunism*[1], wherein with a larger distribution area of a species and a high degree of heterozygosity, changes for passive assemblage are increased, versus *Ecological opportunism*[1], wherein some insects simply exploit hosts constituting a larger resource without particular changes in habitat selection. Host plants are the basis of complex food webs, which can reduce the pressure of phytophagous exploiters. Plant structures as such are arenas for the 'competitive interaction' of the insect species exploiting them. In short, phytophagous insects exert a selective pressure that promotes diversification of defence mechanisms in plants.

Morphological resistance of plants to insect attack, more particularly the role of trichomes, has received considerable attention. Some of these trichomes may interfere with oviposition, attachment of the insect to the host plant and feeding, and their mechanical effects relate to density, erectness, length and shape. Some trichomes possess glands that exude secondary plant substances so that the plant may combine physical and chemical defences. Even if eggs are laid, many larvae do not survive because of the nutritionally inadequate diet. Most plants escape or survive the attacks of insects through the possession of thickened cell walls, increased toughness of tissues, proliferation of wounded tissues, solid stem, trichomes, surface waxes and silica in cell walls. Many plants possess extrafloral nectaries, which serve as attractants that defend the plant against other insects.

ROLE OF ALLELOCHEMICALS

Thousands of chemical compounds that act in one or the other manner are well known, and broadly classifiable into five major categories: nitrogen compounds, primary alka-

1. Zwolfer, H. 1982, *Proc. 5th Int. Symp. Insect-plant Relationships. Pudoc.* Wageningen: 287–296.

loids, terpenoids, phenolics, proteinase inhibitors and growth regulators relating to insect hormones. While allelochemicals in general mediate an interaction between two individuals belonging to different species, kairomones evoke in the receiver a behavioural or physiological response and allomones produce responses favourable to the producer. When the response is favourable to both producers and receivers they one known as synomones. The role of allelochemicals or secondary plant substances, so called because they play no primary role in metabolism, is also well known, although there is an imminent need to identify many more such compounds in as many plants as possible and to assess the importance of their influence on insect-plant relationships. Contact chemoreceptors and close range olfaction within the leaf boundary are significant for insect food selection. But the surface topography and the chemistry on and immediately above the leaf surface are equally important.

Phenolics, which are non-nitrogen compounds containing one or more hydroxyl groups attached to the benzene rings, have a role among the multitude of chemical signals that make up a plant and its environment. They are known to affect the nutritional quality of plants. The major groups of phenolics are phenylpropanoids, flavonoids and quinones. How far plant phenols provide a barrier to insect feeding is a question still being tackled, since they are known to have deleterious effects on larval growth. Dietary phenols may be dealt with by insects through avoidance sequestration/storage, absorption, metabolism and excretion. Compounds harmful to one insect may have little effect on another, even congeneric species. It is still far from clear how phenolics interact with the nutritional quality of the leaf to reduce its palatability. Some phenolics, such as tannins, have strong protein adsorbing properties; proanthocyanins or condensed tannins are feeding inhibitors, which also reduce digestibility; however anthocyanins promote pollinator attraction, and rotenone, an isoflavanoid, has insecticidal properties. Protein inhibitors in plants are found in large quantities in seeds, tubers and foliage, and the inhibitory activity of protein inhibitors is specific to digestive proteinases. Protein inhibitors are proteins or polypeptides that split bonds of proteins inhibiting the proteolytic activity of the enzyme.

Terpenoids, such as mono-, sesqui- and diterpenes possess the maximum range of functioning in the regulation of growth and development in insects. While monoterpenes act as attractants/repellents, sesquiterpenes and diterpenes exhibit considerable biological activity in relation to the action of toxins and hormones produced by plants. These plants are able to synthesise and sequester compounds non-toxic to the plant itself, but on being consumed by insects are activated into lethal cytotoxins. Several growth regulators, such as phytoecdysones and juvabione-like compounds, such as precocenes, have been isolated from plants. In insects feeding on terpene-containing plants, cytochrome P-450 is known to metabolise them to products, which could be excreted; it is equally well known that many terpenes induce cytochrome P-450 to higher activity. Such activities may influence the hormone balance or pheromone products in the insect, so that regulation of reproductive processes by these allelochemics is implicated. Hormonal and pheromonal research both in terms of naturally occurring chemical products in plants as well as intrinsic studies of their impact on the reproductive physiology of insects, would go a long way in promoting a better understanding of non-conventional methods of insect control.

A new class of regulating molecules in plants, oligosaccharides, which help to control growth, reproduction and defence against diseases, were recently discovered. These are fragments of the cell wall, released from the wall by enzymes. Plant cell walls are repositories of a large number of oligosaccharides. These are thought to regulate not only activation of defence mechanisms, but also aspects of plant product and morphogenesis.

There is an increasing need for a deeper understanding of the chemical perception of plants by insects with different host plant selection strategies. Generalists or polyphages use different chemical cues to recognise their preferred host, while the specialist host perception is mediated through key stimuli in their preferred host. By comparing the oviposition behaviour and the sensory physiology of adult insects with different host specificities and by analysing behaviourally active compounds, it has been postulated that the same fractions, which were neutral or stimulatory to specialists were highly repellent or deterrent to generalists. There is need, therefore, to isolate active compounds in order to evaluate their combined effect or interaction on oviposition behaviour. Another aspect relates to the plant stimulating vitellogenesis since in its absence ovarian activity is kept at a low level. If the plant stimulates mating, dependence of the female on the plant is greater, so that the adjustment of fecundity to the carrying capacity of the environment is better. For example, some phytophagous insects do not mate without eating the pollen of particular hosts; thus flowering stimulates vitellogenesis and induces the female to a state for oviposition. Such a stimulation of vitellogenesis will also occur when feeding on other plant parts; there are lacunae in our understanding of this problem. Host plants tend to induce the production of visual, olfactory and auditory stimuli in one sex, and host plant induction of sexual behaviour is an aspect deserving more incisive studies. It is well known that the discovery of larval host plants by adults is a prerequisite for oviposition, particularly by specialist insects.

SEQUESTRATION AND DETOXIFICATION MECHANISMS

Many insects sequester secondary plant metabolites for their own protection. Sequestration mechanisms in phytophagous insects include the acquisition of nutrients, adsorption of specific chemicals by insect chemoreceptors as well as uptake of ions enabling maintenance of osmotic balance. Many phytophagous insects have the ability to metabolise steroids to various degrees prior to their incorporation in the membranes. A host of other physiological processes such as utilisation of dietary phenylalanine and tyrosine for the formation of proteins are well known in some insects. It is also known that each insect species treats ingested plant allelochemics distinctively, so that a compound excreted by one insect becomes the main sequestration product for another. Phytochemicals such as volatile oils sequestered by bees to attract males or as pheromones in lek formation, production of pheromones as in scolytids, or production of gregarisation pheromones in locusts, are important for certain critical behavioural and physiological processes of insects. Well-known examples of sequestration include eugenol, vanillin, pinene and myricine by bark beetles from pine terpenes; and pyrrolizidine alkaloids by danaid and arctiid lepidopterans acquiring male sex pheromones. Sequestration is the result of physico-chemical and biochemical conditions, and involves differential organisation of exogenous chemicals into other molecules, membranes, cells, etc.

Absorption of nutrients by the gut and their subsequent utilisation by the body is fundamental in explaining how these chemicals are incorporated. The sequestration and storage of cardiac and cyanogenic glycosides and other toxic alkaloids and their utilisation in defence against predators are classic examples. Many more such instances await discovery, particularly with emphasis now being given to the role of natural plant products and insect attack. Sequestration represents the end product of a series of biochemical and physiological events, which may reflect absorption, metabolism of specific compounds and excretion of selected allelochemics[1]. The entry of a plant allelochemic into the gut of an adapted insect is known to trigger a series of reactions that may result in the compound being metabolised. Detoxification results from the metabolisation of the absorbed compound and this process often results in the sequestration of a product. Very little is known about the toxicities of allelochemics and their metabolites to be able to assess the significance of these processes.

Metabolic conversion of potentially toxic allelochemics to water-soluble products which can be easily eliminated or utilised or stored is effected by several enzymes—oxidases, hydrolases, transferases and reductases. Since lipophilic foreign compounds are hazardous in view of their large-scale occurrence in plants, these enzymes aid in their conversion from a lipophilic to a hydrophilic condition. Many natural plant chemicals are known to induce Mixed Function Oxidases (MFO) activity, which may mediate resistance. The midgut epithelium has a high potential for MFO production as well as of other detoxifying enzymes. Synergistic chemicals are also known, which may inhibit MFO enzymes. However, this is a relatively new area and not much is known about the functioning of naturally

[1] Duffey, $.$.1980 *Ann. Rev. Entomol*, **25 :** 447–477.

occurring synergists on the consumption and utilisation of plants. The MFO system is also believed to participate in the synthesis of pheromones molecules[1].

Recent efforts to study the antiherbivorous effect of phytoalexins have evoked considerable interest because they affect the feeding preference of adults and larvae of phytophagous insects. In some cases detoxification mechanisms exist to overcome the antibiotic effects of isoflavonoid phytoalexins, but not of substances like rotenone. While studies on the effects of phytoalexins on the feeding of several phytophagous insects have provided diverse results, some, for example vestitol and phaseolin, are known for antifungal activity and reduction of feeding by phytophagous insects. Others such as pisatin, genistin and coumestsrol may affect the feeding of one species, but not of others. Thus phytoalexins exert a selective effect[2]. Hence the role of phytoalexins in plant defences and of the mechanism of induced resistance may be a very potential field for future investigation, particularly because 'induced resistance' represents a new dimension in pest control strategies. Plant properties responsible for deterring the feeding of an insect or non-preference mechanisms, involve antibiosis, wherein the insect is totally prevented from feeding, and antixenosis when it is forced to feed on a particular plant, with no choice. These two reactions are equally important. Resistant plants are known to lack or possess very little of the normal kairomone, which is inhibited or blocked by antagonistic compounds. Antibiosis is the most evident form of resistance, often caused by toxic metabolites, and its effects are larval mortality in the first few larvae, abnormal growth rates, pupation and adult emergence failure, malformed or sub-sized adults, reduced fertility and fecundity, and inability to store food reserves. Whether a potential host is selected or not is therefore decided by a balance between physical stimuli and physical barriers, attractants and repellents, feeding deterrents, ovipositor stimulants and ovipositor deterrents. A good example is the most effective antifeedant and toxicant against many pest insects - azadirachtin – and available information has highlighted its direct role on the neuroendocrine system, as well its inhibitory action on gut motility in *Locusta.* In view of azadirachtin containing several principles, its potential in terms of the isolation and nature of activity of these principles is a fertile area of future research.

The exploitation of plant tissues by insects resulting in the abnormal growth called 'galls', is a specialised level of trophic strategy providing an optimal environment for rapid reproduction and abundant food for the larvae and adults of gall-forming insects. The development of nutritive tissues as well as of other meristematic tissues, capable of differentiation into various tissues, are very typical of gall formation. The biochemistry of gall formation has eluded cecidologists and the several explanations put forward are not very

[1] Ahmed, S. 1983, *Herbivorous insects: Host Selection Behaviour and Mechanisms.* Academic Press, New York, pp 257.

[2] Kogan, K. and Paxton, J. 1983, Natural inducers of plant resistance. In Brattsten L.B and S. Ahmed (ed) *Molecular aspects of Insects Plant Association.* Plenum Press, New York, pp 347.

convincing. Cecidogenesis tends to alter the composition of amino acids in the leaf, raising the soluble nitrogen level and, generally speaking, galling increases the level of total amino acids. Galls are often referred to as sinks withdrawing nutrients and cecidogenetic tissues also have an increased water content. Basically galling can be considered as a reaction to wounding and various hormones play a key role in the wound-induced process. Indoleacetic acid and gibberellic acid are known to accelerate mitosis and the combined activity of various hormones tend to increase kinetin concentration, leading to enhanced proliferation. In-depth investigation of the biochemistry of galling is very much needed to substantiate the several views now current. Equally important is the determination of the significance of plant growth hormones in the further reproduction of phytophagous insects, taking into consideration seasonal changes in the physiological state of their host plants. In addition, the temporal adaptation of the insect life cycle in relation to the phenology of the host plant also appears to be a decisive factor in phytophagous insects with specialised behaviour.

It is difficult to adequately pinpoint the specific parameters involved in insect-plant interactions, more so because the interaction constitutes a continuing process in space and time. With both the insect and the plant trying to outwit the other, the mechanisms involved in this process naturally vary from species to species and it is here that no broad generalisation is possible. Thus the study of as many species of phytophagous insects and their host plant becomes more obligatory, so that in the long run it will be possible to undertake an overall analysis of such interactions with reference to both generalist/specialist insects. The basic fact that a major determinant is the size of an insect's habitat and the distribution of the host plants must be recognised. In the successful achievement of such a colonisation, the qualitative and quantitative chemistry of the living plant in relation to behaviour and sensory physiology play a vital role, offering a better understanding of the sensory physiology in insect-plant relations. In this connection there is also a need to realise that phytophagous insects are regulators of plant growth, playing their role in 'density-responsive' regulation of the population densities and dynamics of the affected plants. The mechanism of resistance is known to a great extent, but gaps still exist in our information regarding the biochemical and genetic adaptations. The emerging frontiers of insect-plant interactions lie, however, in the exploitation of the nature of resistance in crop plants through modern DNA technology, gene splitting and gene cloning.

Ant-Plant Interactions

Ant-plant mutualisms are well developed since they depend on each other to increase their fitness. Ant inhabited plants are called as myrmecophytes. Plants like acacias have enlarged thorns (modified stipules) and ants hollow out these to use as nest sites. In some acacias ants inhabit stem swellings or galls just below the stipular thorns. Ants belonging to the genus *Pseudomyrmex* hollow out large areas of the thorns and distribute the colony among the numerous thorns. Swollen thorn acacias have extrafloral nectaries at the petiole, which secrete a solution containing water, sugar and amino acids. *Beltian bodies* are found at the tip of the leaves, which provide protein lipids for the ants. Ants collect Beltian bodies as soon as they are available. *Pseudomyrmex* colonies contain more than 30,000 ants.

A second group of myrmecophytes receive nutrients from ants and are the ant epiphytes, the plants producing hollow or inflated roots, hollow rhizomes or folded leaves. A plant structure generally inhabited by ants is called domatium. Best studied nutritional myrmecophyte is the plant *Myrmecoelia tuberosa,* with enlarged tubers containing empty broods are kept here and the ants deposit their refuse. Adventitious roots grow into the chambers containing ant refuse and absorb nutrients directly.

Another aspect of ant-plant interaction deals with seed dispersal and ant dispersal of seeds is called myrmecochory. The seeds have associated appendages that serve as food for the ants. For example elaiosomes are oil-containing appendages that are utilised by ants.

◆ Chapter 82

Insects and Host Plant Resistance

Host plant selection is a complex process involving host habitat finding, host finding, host recognition, host acceptance and host suitability. Each one of these major steps maybe influenced by the chemical composition of the host plant, their nutritional quality as well as secondary chemical substances which often play a major role. Other components of host selection involve: (a) insect utilisation of the host plant for food, oviposition, and shelter, (b) the effects of insect infestation of a plant, (c) the effects of the infested plant in terms of insect survival, colonisation, fecundity, growth and population build-up. In order to successfully utilise its host plant the insect must be versatile enough to complete all the normal sequence of events and failure at any step may confer an advantage to the host plant. It is generally seen that insects tend to multiply rapidly on a suitable host, while on a less suitable host plant they seldom prefer to colonise. Even if colonisation occurs they tend to multiply only at a low rate. Such differences in the suitability of host plant utilisation by insect are not only due to the preferences exhibited by the colonising insects, but also due to the inherent qualities of the host plant which facilitates insect colonisation. Thus the host plant forms an important 'island' for the insect, which determines its survival, growth, and multiplication rates. The inherent qualities of the host plant, which help to protect them from insect damages are collectively referred to as 'resistance'. In other words, resistance of plants to insects is the property that enables a plant to avoid, tolerate or recover from injury by insect populations, which would cause greater damage to other plants of the same species under similar environmental conditions. From an evolutionary point of view, resistance traits are pre-adaptive characteristics of plants to withstand the selective pressures of herbivore populations, thus increasing the chances for their survival and reproduction. This means that plants co-evolving with their insect pests must acquire a certain degree of resistance to enable their survival and a precise understanding of such host plant mechanisms for resistance would go a long way in tilling the balance in favour of the crops. The concept of insect resistance to crop plants was initiated by Painter* (1951), who recognised three basic components of resistance:

Preference/Non-preference: lnvolving plant characteristics that make it unattractive to insect pests for oviposition, feeding or shelter;

Tolerance: Referring to the capacity of certain plants to withstand the injury caused by the insects and to produce an adequate yield in spite of supporting an insect population at a level of damaging a more susceptible host; and

Antibiosis: Encompassing all adverse physiological effects on the life history of the insect of a temporary or permanent nature resulting from the ingestion of a plant by an insect, leading to decreased fecundity of size, increased mortality or shortened life span.

Though the concept of resistance was merely related to genotypes, it is equally well recognised today that resistance can be affected considerably by the condition in which the crop is grown. The degree of previous infestation, age or height of the plant may influence preference. The suitability of the plant for growth, survival or reproduction of insects has also a direct relationship with water stress, growth regulators, nature of fertilisers used, etc. In brief, the mechanisms of resistance to insects by plants are principally physiological, but subject to environmental variation. As such plant resistance to insects is complex and is seldom caused by a single mechanism or a single chemical. Plant resistance could also result from disruption of the normal sequence of events because of a reduction in the level or repression of the kairomones, or because of the enhancement of allomones. While some resistance traits are under genetic control, others may be viable and fluctuate widely under the influence of environmental conditions. Hence, the mechanism of resistance may be classified as those that are under the primary control of environmental factors (ecological resistance) and those that under the primary control of genetic factors (genetic resistance).

Ecological Resistance

Ecological resistance does not result from genetic characters inherent in the host plant, but from some temporary shifts in the environmental conditions favourable to the otherwise susceptible host plant. Painter (1951) has classified ecological resistance as 'Pseudo-resistance', since plants that escape insect attacks by this mechanism may in fact be susceptible if the pest occurs at the right time. Pseudoresistance may be further classified into 'host

* Painter, R.H. 1958. Resistance of plants to insects. *Ann. Rev. Ent.,* **3**: 267–290

evasion' and 'induced resistance'. Survival of an oligophagous insect, on a plant is not only determined by the selection of the right host plant, but also of the proper stage of development. The phenologies of the plant and of the insects must be synchronised so as to enable a plant structure to exist, when a particular stage of the insect needs it. However, an alternation in plant growth patterns that result in asynchronies of insect-host phenologies result in a type of resistance called as 'host-evasion'. The characteristics of resistance are also bound to vary with the age of the crop plants. Phytophagous insects directly depend on their host plants for food and the more specialized the association, the greater is the 'physiological dependence' of the insects upon the plant. Synchronies may be induced by early or late planting of certain plant varieties. The early varieties of soybeans planted were found to escape from the attack of the bean leaf beetle, *Ceratoma trifurcata*, since by the time the beetle emerged in the early part of September, most plants had already matured, being ready to harvest. Thus these beetles cannot harm the crops, since the mature pods are not an adequate food. Early sowing of the castor variety Dominica resulted in lesser infestation and 'hopper burn' from the leafhopper, *Empoasca flavescens* than those sown late in the season.

Certain environmental conditions may tend to alter the physiology of a plant to such an extent that it becomes unsuitable as a host. Under such conditions the responses of crop plants to normal cultural practices such as fertilisation and irrigation may be altered to bring about drastic quantitative or qualitative changes, making the host plant unsuitable for colonising insects. In other words products made and intentionally applied tend to influence the behaviour of insect, to plants. These products include, apart from fertilisers herbicides, fungicides, growth regulators and insecticides. For example, at high nitrogen levels, insects usually respond with an increase in survival and faster rates of development. Aphids are particularly sensitive to the levels of potassium, even in the presence of high nitrogen. Thus the possibility of bringing a balance between nitrogen and potassium could induce the crop plant to combat the pest attack Similarly, application of Maleic hydrazide to broad bean plants increased mortality and reduced fecundity of aphids and growth retardants such as chlormequat also have been known to appreciably increase resistance mostly due to reduced fecundity of females or increased mortality of offspring. Another interesting induced resistance factor is induction of resistance involving accumulation of compounds with resistant populations, as for instance, feeding by the pea aphid on alfalfa induces an increase of coumestrol that may affect feeding by other pea aphids. Other examples are production of phenolics by cotton bollworm on cotton, cucurbitacins by the striped cucumber beetle on squash etc. Mechanisms of induced resistance relate to changes in the physiological status of the plant, in the nutrient concentrations, in the concentrations of allelochemicals, and the most significant of all, the *de novo* synthesis of phytoalexins.

Genetic Resistance

Genetic resistance includes mechanisms based on whole expression of inherited characters which although influenced by the environment, is not strictly under environmental control. This includes non-preference, antibiosis and tolerance mechanisms of resistance. However, in the strict sense the term 'non-preference' refers to a behavioural response of the insect to a plant, whereas 'antibiosis' and 'tolerance' refer to plant characteristics. The term 'antixenosis' is used to describe the plant properties responsible for non-preference. If a plant deters feeding by an insect, the mechanism of resistance may be classified as 'antixenosis' or 'antibiosis', the choice of a host plant being affected by an array of positive and negative factors. The positive factors include the undesirability of the host plant (antixenosis) leading to the avoidance by insect because of the absence of certain physical stimuli, attractants, feeding stimulants, and ovipositional stimulants. The negative factors include the unsuitability of the plant (antibiosis) or the host plant preventing the activity of insects due to the presence of certain physical barriers, repellents, feeding deterrents, and ovipositional deterrents.

Non-preference

The phenomenon of non-preference is the first and foremost step operating in the catenary process underlying host plant selection by any phytophagous insect, when the insect has located its host plant. For an understanding of the mechanism underlying non-preference, the behaviour of the insect should be thoroughly understood. The behavioural responses shown by insects due to the undesirable attributes of the host may be due to physical, chemical or environmental factors, which restrict the insect utilising the plant for normal feeding and oviposition. At least two types of non-preference have been observed viz. one, which can be manifested only in the presence of the preferred host, and the other that can be demonstrated in the resistant plant even in the absence of the preferred host. For instance, the tobacco hornworm, *Manduca sexta* refused to feed on preferred plants, but larvae with maxillae removed sometimes consumed the plants without any adverse effects.

In most phytophagous insects non-preference due to oviposition and feeding generates a series of complex responses depending upon the environmental features and host characteristics. As applied to resistance, non-preference may represent one or more breaks in the chain of responses leading to feeding or oviposition. These breaks could be: (a) the absence of arrestant or attractants; (b) the presence of a repellent; or (c) an unfavourable balance between arrestant and or attractant on the one hand and repellent on the other.

Hence, the chemical composition of the plant is of fundamental significance in their acceptance or rejection of food or oviposition by insects. In many cases feeding inhibitors are of primary importance in determining the plants susceptibility to consumption.

(a) Non-preference due to Physical Factors The physical factors influencing non-preference include visual and tactile stimulus. Among the visual cues affecting orientation of insects towards a host plant, colour and shape appear to be important. Insect attraction to foliage colour has been most intensely studied in homopterans. In some aphids, discrimination between plants or portions of plants in particular physiological conditions may be at least partly accomplished on the basis of differences in saturation of intensity or reflected light. With respect to saturation in the aphid, *Hyalopterous pruni* seeking plants like *Phragmites* as summer hosts, they alight in greater numbers on unsaturated yellow than on saturated yellow. They appear to use the same saturation discrimination basis for discerning their unsaturated *Phragmites* host from non-hosts. With regard to intensity differences, some aphids are more attracted to higher reflectance from newly developing leaves (the yellow appearance correlated with high available nitrogen content of the sap) than to the lower reflectance of mature green leaves of the same plant. The apple maggot fly, *Rhagoletis pomenella* is also attracted to the yellow hue of foliage for feeding and resting and to the form of the fruit for mating and oviposition. The behavioural repertoire of the onion fly *Delia antiqua* suggested that apart from chemical cues, visual and structural cues are also important in stimulating egg deposition by the insect. Thus for herbivores that respond positively to the visual stimulus of foliage reflectance, green pigments, and to a much greater extent yellow pigments, have proven valuable in management programmes against various homopterans, beetles and flies when incorporated into traps for monitoring or direct control. Similarly, for insects attracted by the form of host plants or plant structures, mimics of appropriate shape, size, and hues, alone or in combination with olfactory stimuli, have constituted powerful methods of population monitoring or direct control.

(b) Non-preference due to Morphological Factors The morphological factors interfere physically with locomotor mechanism and more specifically with the mechanisms of host selection, feeding, ingestion, digestion, mating and oviposition of insects. Such physical barriers are also mediated by the presence of trichomes, surface waxes, silication, or sclerotisation of tissues. In addition, allomones affecting insect behaviour and metabolic processes may occur in plant morphological structures (trichomes on bracts).

Plant pilosity was frequently postulated for being involved in susceptibility or resistance to insects. The most notable success was the control of the cotton jassid, *Empoasca* spp., by means of plant resistance to oviposition. Growing soybean varieties with dense hairiness of foliage manifested both preferences and resistance to leafhoppers. Studies on the resistance of castor (*Ricinus communis*) to the leafhopper, *Empoasca flavescens* showed that the infestation of the insect was directly or indirectly related with plant characters of castor varieties. Jassid incidence was found to be positively correlated at a highly significant level with the plant height, intensity of waxy bloom coating, leaf area, age of the plant at flowering, number of nodes, internode length, petiole length, leaf sinus depth and number of leaf lobes etc. For feeding and oviposition the insects preferred Dominica (susceptible and C3). In addition, hoppers preferred middle and bottom leaves rather than the top leaves within the plant. Besides hairiness, various other characters like, the width of leaves and palisade tissue, thickness of midveins, density of trichomes and angle of insertion of trichomes also had an impact on resistance or susceptible behaviour of varieties of cotton to jassids.

The bollworm, *Heliothis zea* showed preference for extremely pubescent rather than smooth cotton plants. On the contrary, the oviposition of the leaf beetle, *Oulema melanopus* was not only low in pubescent varieties, but the oviposited eggs also were susceptible to dessication and only less than 10% hatched. Some insects also exhibited preference for either smooth or rough surfaces. For example, the cowpea bruchid, *Callosobruchus maculatus*, prefers smooth coated and well-filled seeds to rough and wrinkled varieties for oviposition.

In many cases the nature and distribution of epidermal trichomes and glands protect crop plants from the attack of insect pests. Glandular trichomes and plant glands exude sticky substances that entraps and immobilises small insects, or they may contain toxic constituents which spill into the surrounding tissue when the glands rupture, making the plant unpalatable for insects. The wild *Solanum* species, *Solanum berthaultii* and *S. polyadenium* are defended by glandular trichomes on its foliage, secretions of which entrap and immobilise the green peach aphid, *Myzus persicae*, the potato aphid *Macrosiphum euphorbiae*, and the potato leaf hopper, *Empoasca fabae*. Two types of glandular trichomes were identified to be associated with insect resistance, a short type with a four-lobed gland at its apex (type-A), and a longer multicellular trichome with an ovoid gland at its tip. Mortality of fourth-stadium *M. persicae* and encasement of tarsi and labia by type-A exudate increased with a rise in density and volume of type-A trichomes. Similarly, wild tomato, *Lycopersicon hirsutum* f. *glandulaum* is covered with trichomes, which contain 2-tridecanone, the level of which is much lower in the domestic varieties. This substance proved toxic to *Manduca sexta* and *Heliothis zea* and this toxic compound was significantly more abundant on foliage of plants grown under long day regimes.

DIMENSIONS OF INSECT-PLANT INTERACTIONS

Several morphological and anatomical characteristics of potential host plants may present barriers to insect feeding and oviposition. Resistance to the striped rice borer, *Chilo suppressalis* (Walk.) was observed in rice varieties whose leaf sheaths had closely packed vascular bundle sheaths and a large number of sclerenchymatous layers, and in rice plants whose stems and leaf sheaths contained high amounts of silica. The larvae feeding on rice varieties containing high amounts of silica exhibited the typical antibiosis effects and worn-out mandibles. Anatomical characteristics that confer resistance are hard wood stem with closely packed, tough vascular bundles, making larval entry and feeding difficult. In sorghum all resistant varieties were characterised by a distinct lignification and thickness of cell walls enclosing the vascular bundle sheaths within the central whorl of young leaves. Similarly, the mechanism of resistance in brinjal to the shoot borer, *Leucinodes orbonalis*, was attributed to compact vascular bundles in thick layer with lignified cells and low pith area.

Another good example is the interaction between the onion thrips, *Thrips tabaci* and varieties of onion. Of the many varieties tested, 'White Persian' was outstanding in its resistance showing only little injury. Two or three characters tend to restrict onion thrips population viz., shape of leaves, angle of divergence of the ten innermost leaves and the distance apart of the leaf blades on the sheath column. In most varieties the leaf blades are flat and the two opposite blades are closely adhered protecting the larvae. In the 'White Persian', the leaves are circular in circumsection reducing protection to a minimum. The wide angle between the two innermost emerged leaves in young plants help to restrict the population and there is a greater vertical distance between leaf blades restricting the sheath column.

(c) Non-preference affecting Oviposition Most phytophagous insects deposit their eggs on or near the host plant to be utilised by their progeny. Oviposition is the culmination of a series of behavioural events, the first component of which is the orientation of the gravid female to the prospective host plant, which is selected from among the array of plants available. Following orientation to the plant as a whole, the insect orients to different plant parts in the selection of a specific oviposition site. Plant characteristics tending to prevent oviposition may do so by failing to provide the appropriate stimuli for orienting towards the host plant or for ovipositing the eggs.

Orientation to a prospective host plant may involve normal as well as chemosensory stimuli. The importance of plant-borne attractants in insect orientation has been demonstrated in many studies, and the role of olfactory stimuli in some instances of plant resistance has also been confirmed. For instance, an up-wind orientation of desert locust in response to grass odours has been reported. The odours of non-hosts may fail to evoke any orientation response, or they may elicit a negative reaction in which the insect moves away from the odour source. Upon arriving at the prospective host plant, the insect is responsive to stimuli that will release the subsequent components of the ovipositional behavioural pattern. Oviposition is seldom indiscriminate over the surface of the plant or in the surrounding soil, but most frequently on selected plant parts. The specific sites selected may vary according to leaf maturity and the physiological state of the plant. Specific ovipositional stimulants may he involved such as a stimulant for the carrot root fly, *Psila rosae*, was found in carrot leaves and identified as trans-1, 2-dimethoxy-r-propenyl-benzene. Oviposition by the onion maggot was stimulated by a number of organic sulphur compounds, most effective of which was n-propyl disulphidede and n-propanyl mercaptan, both of which are normal constituents of onion.

The role of inhibitory stimuli in the choice of oviposition site by phytophagous insects has been emphasised. The acceptance or rejection of a plant usually depends on contact with the plant surface or through probing after landing. Specialist insects will oviposit if the right stimulant is present, whereas acceptance by generalist is governed to a large extent by the absence of deterrents. Specialists may also be deterred by non-host components, which can interfere with the response to positive signals.

Non-preference to Feeding The feeding behaviour of phytophagous insects is an important factor in determining the resistance of host plants to the attack of insects. Insect larvae hatching from eggs deposited on a host plant are usually confined to that plant for the whole of their immature, feeding stages. Feeding involves a series of stereotyped behavioural components and such behavioural pattern is manifested only in response to the appropriate combination of external releaser stimuli. The host plant is normally the source of releasing stimuli, and resistance may result from failure of the plant to provide the stimuli required for one or more components of the sequence, or because the plant provides adverse stimuli that tend to prevent the release of the behaviour.

The range of food plants of an oligophagous insect has, in a number of instances been shown to be characterised by the presence of identical or related chemicals that stimulate the insects' feeding. The classical demonstration of the relationship of the feeding specificity and taxa-correlated chemical factors is the instance of larval feeding of *Papilio ajas*. Umbelliferae, on which this butterfly feeds almost exclusively, contains a group of related essential oils that attract the larvae. Plants not containing these substances were not attractive, nor would the larvae attempt to feed on them. Similarly, feeding of larvae of *Plutella xylostella* is confined entirely to the plant family Cruciferae; a number of mustard oil glucosides that commonly occur in cruciferous species were shown to be feeding stimulant for the larvae. In addition to the nutrients a number of secondary plant substances are involved in such cases of specialisation, even though the primary function of these compounds in the evolution of the plant is believed to be in defense against herbivores. Such compounds are powerful feeding deterrents or antibiotic agents providing protection from generalist insects. The idea of utilising feeding deterrents as a means of protecting crops from insect damage has received a lot of attention in the last few years, and large screening programmes have uncovered several promising compounds present in plants, and the introduction of feeding deterrents into crop plants through breeding programmes would appear to be an ideal solution to many pest problems.

Antibiosis

When a plant is resistant by exerting an adverse effect on insect growth and development, the nature of resistance is termed as 'antibiosis'. The adverse physiological effects may be of a temporary or permanent nature and mostly inflicted due to the presence of certain toxic compounds present in the host plants. The chemical basis of plant resistance can be viewed from two perspectives; a plant may be resistant owing to the presence of certain plant chemical(s) such as growth inhibitors, feeding deterrents repellents and physiological toxins or because of the low concentrations or absence of certain chemicals such as essential nutrients, feeding stimulants, attractants, etc.

(a) Presence of certain Growth Inhibitors A unique example of the significance of a plant chemical in plant-insect interaction has been demonstrated in cotton. For instance the inhibitory effects of four types of cotton constituents, condensed tannis, flavanoids, terpene aldehydes and cyclopropenoid fatty acids, upon the larvae of *Heliothis virescens, H. zea* and *Pectinophora gossypiella* appears to be striking. Breeding cotton varieties with increased gossypol content render the plant virtually immune to most of its lepidopterous pests. Larval growth was found to be greater on glandless than glanded cotton strains. The antibiotic activity of gossypol, tannins, and anthocyanins have also been assessed on the spotted bollworm, *Earias vittella.* The cotton constituents that show antibiotic activity towards insect pest are biosynthetically produced through either the acetate or shikimic acid pathways. In the case of glandless varieties, which do not contain high concentration of gossypol, a different factor is responsible which protect the plants from the attack of lepidopterous larvae. It is now found that condensed tannins can suppress *Helicoverpa* larval growth, development and reproduction. Anti-growth activity of condensed tannins appear much more effective for early larvae of *Helicoverpa.*

Tannins have been considered as an important secondary plant component responsible for acting as feeding deterrents against several herbivores. There are in fact two groups of tannins. The hydrolysable tannins and derivatives of simple phenolic acids such as gallic acid and its dimeric form, hexahydrocydiphenic acid, combined with the sugar, glucose. The condensed tannins have a higher molecular weight and are oligomers formed by condensation of two or more hydroxyflavanol units. The protein- precipitating properties of the tannins in ingested food result in poor digestion and consequently effectively reduce the nutritive value of the food. They combine with protein, often irreversibly, by forming bonds with the peptide and other functional groups and such bonding prevents proteins from being attacked by trypsin and other digestive enzymes. The importance of tannins in controlling the feeding of winter moth, *Opheroptera brumata* larvae on oak trees has been established. The oak caterpillars feed on the leaves in the spring but abruptly ceases feeding in mid-June, turning to other tree species for sustenance. It was established beyond doubt that the immediate cause of the change in feeding habit in the winter moth is due to the increasing repellency of the leaf; the tannin and protein, normally compartmentalised in different parts of the cell are brought together and the protein undergoes complex formation. As tannin content increases during the season, more and more of the protein becomes complex. This seriously reduces the digestibility of proteins.

The weevil, *Hypera postica* feeds almost exclusively on *Medicago* spp. and occasionally on the related *Melilotus* and *Trifolium.* The rejection of other Leguminosae was due to the presence of high concentration of coumarin. Feeding deterrents including demissine, dihydro-o-solanin, leptines, solacaulin, solanin, and tomatin from various species of *Solanum* for the Colorado potato beetle, *Leptinotarsa decemlineata* have been recognised. It is interesting that deterrence to beetle attack is closely dependent on chemical structure and small changes in part of the deterrent molecule acts on the insect at the membrane level, which are required by the beetle for ecdysone synthesis. Since alkaloids of *Solanum* are in fact steroidal molecules, it is also possible that they have a direct effect in blocking ecdysone biosynthesis. Information on the deterrent properties of demissine is clearly of practical value since breeding experiments with *S. demissum* and *S. tuberosum* yields resistant varieties to the beetle attack.

Several deterrents to insect-feeding isolated from weed and crop plants were found to be very effective pest control agents. For example, a hexane extract of the seed of neem, *Azadirachta indica* and several of its chromatographic fractions significantly deterred feeding by three species of scale insects, citrus red mites and woolly whiteflies, a pentane extract of nutmeg, considerably deterred feeding by adult boll weevils, while an ether extract deterred feeding by adult boll weevils. Many diterpenes and triterpenes have antifeedant properties, those that are more oxygenated being more efficient viz., Azadirachtin against many insects like *Schistocerca*, clerodendrin (from *Clerodendron*) against *Spodoptera litura* etc. Two diterpenes from *Cinnamonum zeylanicum* possesses ability at low concentration to inhibit larval ecdysis in *Bombyx mori.*

Soluble silicic acid was isolated as a sucking inhibitor for the brown plant hopper, *Nilaparvata lugens* from water-soluble extracts of rice leaf sheaths. Silicic acid is presumed to be concentrated in the peripheral tissues outside the phloem and to play a significant role in the localisation of sucking sites in the host by preventing an erroneous intake of parenchyma cell sap. In addition, oxalic acid was another substance identified as sucking inhibitor from rice plants, with special reference to the varietal resistance of rice to the brown plant hopper. Other organic acids such as maleic acid, itaconic acid, benzonic acid and salicyclic acids were also found to be strong sucking inhibitors. Among the decarboxylated derivatives of aromatic amino acids, phenethylamine, tyramine, and hordenine were found to exert a marked sucking inhibitor effect. In addition recent investigations on the chemical factors involved in varietal resistance of rice to the brown plant hopper showed the existence of oxalic acid in significant amounts in resistant varieties compared to susceptible ones.

(b) Presence of certain Toxic substances Deterring Feeding A wide range of chemicals occurring in the host plant have been tested on the short term feeding effects (feeding deterrence) and long term physiological effects (impairing growth and development) of acridids. When extracts of 187 graminivorous species were provided, *Locusta migratoria* rejected 98 of them due to unpalatability. In the polyphagous species, *Melanoplus bivittatus* it was found that several secondary compounds, including alkaloids, a glucoside and a saponin, inhibited drinking behaviour and reduced the food intake. Sometimes morphological differences also results from feeding on different plants, the most obvious being wing development. It has been observed that a relatively high proportion of brachypterous adults were produced in adult *Schistocerca* if the nymphs were fed with Lucerne. Instances such as nymphs of *Zonocerous variegatus* surviving less on *Newbouldia*, extracts of *Medicago* added to diet causing increased mortality to the first instar of *Melanoplus femurrubrum* and substances like nornicotine, solanine, tomatine, digitonin or saponin added to the diets, in amounts equivalent to those in plants, inhibited the survival of acridids are some of the other antibiotic effects.

Not only structural analogues of amino acids, but also essential amino acids themselves can be deleterious, if they are ingested in excessive quantities or if they are not in balance with other amino acids. Ironically, the indispensable amino acids are generally less well tolerated in excessive amounts than are the dispensable ones, but non-protein amino acids are certainly much more toxic than protein amino acids.

Certain 'antivitamins' are also reported to inhibit insect growth. The active compound in fern was identified as an enzyme (thiamase I) that breaks down thiamin. Bracken fern also contains caffeic acid, which has antivitamin activity. Similarly catechol has also been reported for its growth inhibiting and toxic effects on insects. In addition, plant compounds known to inhibit trypsin and chymotrypsin (protease inhibitors) are found in peas, corn, barley and a wide variety of other plants.

Tolerance

Tolerance represents the relative ability of a plant to suffer loss of yield due to its innate capacity to grow and reproduce itself or to repair injury to a marked degree, than that manifested in an equally susceptible host variety. Tolerance is a promising candidate in the pest management programme because of certain innate advantages. Firstly, it enables the host to withstand damage without the use of chemicals to decimate the pest populations. Secondly insects are not known to have developed counter-measures to combat it successfully unlike the development of more virile and aggressive new biotypes for overcoming non-preference and antibiosis. Tolerance is also a natural agronomic procedure that reassert the stability of environment vis-a-vis the perennial host and the pathogen.

Tolerance, like other resistance components is relative and may occur in varying levels. It may also occur in combination with other components of resistance. Tolerance may thus be defined as the level of pest infestation that cause economic loss to other varieties of the same host species. It has also been considered to be a specific/discriminatory (monogenic) resistance as a means of protecting plants from pest damage. Several varieties of rice have been developed with tolerance against the brown plant hopper, *Nilaparvata lugens* based on characters such as plant damage, plant weight loss and yield reduction due to insect injury.

Several chemicals have been found to be responsible for the non- preference mechanism in resistant plant varieties through non- preference for oviposition and allied activities for successful establishment of an insect species on a crop. The phenolic resistant principles present in the host plant tissues of such crops on *Gossypium hirsutum, Abelmoschus esculentus* and *Cajanus cajan* and the antibiotic effects of some cotton resistant principles such as resorcinol, gallic acid and phloroglucinol on *Helicoverpa armigera* are well known. Further the significance of the cotton resistant principles such as tannic acid and pyrogallol to *Helicoverpa armigera* and *Spodoptera litura* appear to be species specific.

◆ Chapter 83

Insects-Weed-Crop Interactions

The wild ancestors of crop plants or original wild races have been the basic material from which the crops of today have evolved. Similarly grain and oil crops and vegetables are known to be evolved from wild weed species. For example, the oat *Avena sativa*, is derived from the wild weed *Avena fatua. Panicum miliaceum*, the millet is evolved from the weed *Panicum spontaneum*, while the Italian millet *Setaria italica* was evolved from barnyard grass *Setaria viridis*. Ragi (*Eleusine coracana*) originated from the weed species *Eleusine indica.* So in many of these cases weeds serve as reservoirs of variability and through occasional hybridisation are able to exchange genes. It is, therefore, natural that wild germplasm is always involved in order to produce more productive as well as disease resistant varieties such as *Oryza andamanensis*, the wild rice, which is rust resistant. Similarly resistance to plant hoppers in *Oryza officinalis*, a wild rice species, has been transferred to *O. sativa.*

However, weeds are so prevalent that they are an important component of agroecosystems. The fact that many pest species colonise on weeds, and breed successfully reveals that they can migrate to the crop and inflict severe damage at any time. This is more so when the growing period of crop plants synchronise with that of the weeds. Instances where there are definite host-plant successions between crops and weeds are also on record. Thus a knowledge of the nature of colonisation of insect pests and their population build-up on crop and weed hosts become essential to understand the interactions between insects, crops and weeds.

Acridid-Weed-Crop Interactions

Weeds provide large, probably an overwhelming, proportion of food for the desert locust, *Schistocerca gregaria* and thus this natural vegetation is effectively exploited by the continually nomadic populations of this pest. In view of the preference of *S. gregaria* for breeding in arid areas that are dry and therefore unsuitable for the growth of crop plants, wild weed hosts occurring in abundance in these locations assume an important role in the ecology of the desert locust.

Although in general, grasshoppers like *Oxya nitidula* prefer graminaceous and cyperacous hosts, conforming to the 'graminivorous type' of acridids, the developmental stages show feeding preferences in terms of the first and second instar larvae feeding on weed hosts and the third, fourth, and fifth instar larvae prefering to feed on crop plants. On the other hand, the cotton grasshopper *Cyrtacanthacris ranacea* feeds exclusively on malvaceous hosts including crops like *Gossypium hirsutum* and *Abelmoschus esculentus* as well as on weeds like *Abutilon indicum* and *Sida rhomboidea*, displaying a regular movement between the crop plants and weed hosts depending upon their seasonal availability.

Truxalis indicus feeds exclusively on monocots specially grasses, while *Orthacris maindroni* feeds on dicots and *Atractomorpha crenulata* on both monocots and dicots.

Aeolopus thalassinus, recognised as a pest of fibre crops, besides showing differences in the rate of development when fed on different weeds, viz. *Cyperus rotundus, Panicum maximum* and *Cynodon dactylon*, also varies in biotic potential with the maximum fecundity shown when fed on *C. rotundus.*

Thrips-Weed-Crop Interactions

The nature of weed-crop interactions with respect to the seasonal fluctuation of insects has been investigated in detail in phytophagous Thysanoptera. The role of the weed *Chloris barbata*, abundant in fields of *Pennisetum typhoideum*, as an alternate host of *Chirothrips mexicanus* is well known. The inflorescence of *Echinochloa crusgalli* also harbours numerous adults and larvae of *Haplothrips ganglbaueri*, the weed acting as an important alternate host for the thrips in paddy fields. *Caliothrips indicus* an important thrips pest of groundnut, is also found to colonise in large numbers on the weed host *Achyranthes aspera*, almost throughout the year, although its infestation on groundnut is seasonal. In Tamil Nadu, groundnut is grown twice a year, as irrigated and rain-fed crop, infestation of thrips was evident on 15 to 20 days old seedlings. The annual weed, *A. aspera* usually appears by August in groundnut fields and acts as a reservoir for this pest. The density of this weed declines from March and with the onset of the crop in June, *C. indicus* migrates from *A. aspera.* The peak population of the pest, both on the crop as well as on the weed was evident during September. With the increase in weed density there was a rapid migration of *C. indicus* from the crop to the weed. Similarly, *Zaniothrips ricini*, another thrips pest of castor, *Ricinus communis* has also been noticed to utilise the weed hosts, *Datura stramonium* and *Calotropis gigantea*. On castor, *Z. ricini* appeared during October and by January the peak population was evident with a decline thereafter. This decline of *Z. ricini* population on castor was immediately followed by the appearance of thrips on *Calotropis* and *Datura stramonium*. In this case both the weeds act as alternate hosts only for about two months.

Lygaeids-Weed-Crop Interactions

The milkweed bug, *Spilostethus pandurus* besides feeding on the crops *Gossypium hirsutum* and *Sorghum vulgare* is recorded as a pest of gingelly (*Sesamum indicum*). Similarly, the milkweed bug, *Spilostethus hospes* was observed causing damage to the seeds of *Solanum melongena, S. nigrum, Helianthus annuus* among the crop plants, besides feeding on the milkweed *Calotropis gigantea* and the weed *Vernonia cinerea*. Regular population monitoring indicated that the weed hosts served as reservoirs to sustain the population until the favourable crop season.

The nature and extent of survival, growth and reproduction of insects on crop and weed hosts ensures not only the suitability of the crop for the colonising species of insects, but also reveals the ability of different weed species to harbour different species of insects. The growth rate and fecundity of the lygaeid, *Oxycarenus hyalinipennis* and the mirid, *Cryptopeltis tenuis* showed significant differences when colonised on crop and weed hosts . Apart from cotton, *O. hyalinipennis* feeds on a number of alternate malvaceous host plant seeds viz. *Abelmoschus esculentus*, *Abutilon* sp., *Sida* sp. etc. The growth rate and fecundity were highest when reared on cotton seeds, than on other host plants. Similarly, the survival, post-embryonic development and reproductive efficiency of the tomato mirid, *C. tenuis* on crops and weed plants appear equally effective.

Host Plant Switching

Another aspect relating to the population patterns of insects on crop and weed hosts is host plant switching which is normally encountered when the crop/weed dries up, the exact stage of the host plant is not available for the insect to feed, or if there is any nutritional inadequacy so that insects tend to disperse to plants of more nutritive value for feeding and breeding. For example, assessment of the population trends of the mirid bug, *Cyrtopeltis tenuis* on tomato (*Lycopersicon esculentum*), ash gourd (*Luffa cylindrica*) as well as on the weed hosts, *Cleome viscosa* and *Gynandropsis pentaphylla* revealed a definite pattern of host plant switching depending upon the host plant availability and maturity. Peak population of *C. tenuis* on ash gourd occurs during May, declining rapidly during June and July.

By the end of July, ash gourd is removed from the field. The bugs then disperse from the cucurbitaceous plants and colonise on the weed, *Cleome viscosa.* The decline in population during June and July is related to the senescence of the vines. Population of *C. tenuis* increases on *C. viscosa* during August, but from September to November they disperse to another weed host, *G. pentaphylla.* As the cultivation of tomato takes place from December to January the bugs move on to these plants for subsequent feeding and breeding. The population slowly increases on tomato and reaches its peak during February and is at a low level up to the end of April, thereafter subsequent dispersal to ash gourd during May is observed depending upon the availability of host plants.

Weeds Harbouring Natural Enemies of Pests

Many instances can be cited with regard to natural enemies with free living stages that feed on the pollen and nectar of wild plants and with predatory/parasitic stages that feed on prey or hosts on wild plants. Flowers of many weed plants provide sumptuous food for natural enemies, for example, adults of some Syrphidae and parasitic Hymenoptera. The giant ragweed, *Ambrosia trifida*, is recognised as supporting a host of the first generation of the parasitoid, *Lydella grisescens*, which then causes notably increased parasitism of European corn borer, *Ostrinia nubilalis. A. trifida* also supports an important host of parasitoids of boll weevil, *Anthonomus grandis* and Orient fruit moth, *Cydia molesta.* The syrphids, *Melanostoma* spp. laid more eggs on brassicas infested with weeds than on weed-free brassicas.

Although several researchers have demonstrated that certain weeds serve as reservoirs of alternate hosts and prey for natural enemies, only a limited number of weeds appear to be tolerated in fields of cultivated crop plants since the weeds can hamper the economic threshold level and compete with the crop. Hence the trend envisaged now is to maintain certain specific weed associations in crop areas to provide supplementary food for entomophagous insects. However, the objective of maintaining a desired weed composition at a limited density has been seldom achieved. The use of weeds in vine yards of California to manage the grape leaf hopper egg parasitoid *Anagrus epos* was in vogue.

Many of the predators can be increased through seasonal manipulation of selected weeds and effectively used as natural enemies of important crop pests. Early stages of crop growth, the presence of specific weeds may act as a reinforcement for natural enemies of crop pests. They thus sustain the population of predators prior to the onset of the pest. Later these control agents tend to migrate from the weedy areas to the crop. For example, most of the predators like *Geocoris* spp., *Podisus maculiventris*, *Zelus cervicalis, Callida decora*, etc., and several coccinellids, syrphids and dolichopodids are seen on weeds like *Solidago altissima, Chenopodium ambrosoides* and *Heterotheca subaxillaris* in spring and later occur on corn in nearby fields. A chemical interaction between the leaf hopper, *Empoasca kraemeri* and two grass weeds *Eleusine indica* and *Leptochloa filiformis* was noticed when grown on the boundaries of the bean field exerting a repellent and/or masking effect decreasing its colonisation efficiency. Weeds also play an important role in reducing crop apparency and increasing the anti-herbivore chemical defence of certain crops.

◆ Chapter 84

Signalling Chemicals: Pheromones

The intermittent flashings of fireflies and glow-worms and the chirping of crickets are well-known signals attracting mates, but long distance mating calls involves chemical odours and the chemistry of sex attraction has drawn the attention of entomologists the world over. Chemical signals control insect behaviour, the signals involving volatile organic substances active in very small amounts, released by one insect to affect another of the same species.

Pheromones, as these substances are called, are involved in every aspect of insect life, feeding, sex, aggregation and oviposition, so that chemical communication in biological systems has come to be widely recognised. Chemical signals form an universal attribute of life existing within cells, within and in between organisms. Together with acoustic and visual modes of communication, chemical signals of the olfactory type such as pheromones serve an enormous variety of purposes, particularly in relation to feeding, reproduction and protection.

In social insects as in honey bees, they are essential means of communication between the castes. A practical incentive for the study of insect pheromones is evident since their identification provides a means of monitoring population of major pests of agriculture and forestry.

Naturalists of yesteryears were intrigued by the ability of female moths to attract males over long distances of several kilometres and it was in the thirties that this attractivity was identified as due to volatile chemicals, the functional antennae of the moths being critical for the location of females. The complexity and variety of chemical structures observed in diverse insect species point to the amazing ability of insects to sequester and synthesize unique chemical blends. It was in1939 after 30 years of ceaseless research that the Nobel Prize winner Butenandt identified the sex attractant of the silk moth as Bombykol, extracted from half a million female silkworm pheromone glands.

This was the beginning of our understanding of biocommunication in insects leading to a better appreciation of signal systems, their decoding and utilisation as adaptive strategies. The communication system involves release of specific chemical from a producer or emitter, the transmission of these chemicals in the environment to a receiver and processing of the signals to mediate appropriate behavioural responses in the receiver. These chemical messengers have a two-way action – a releaser effect including such types of behaviour as alarm behaviour, trail following, aggregation, dispersion: and a triggering effect, kindling a chain of physiological events in the receiving organisms controlling such phenomena as caste determination.

Sex pheromones are so called because the compounds liberated by a female have a dual purpose of both attracting the male from a distance and also inciting it for mating, not to mention of substances produced by males to excite females. The extensive application of pesticides which has upset the delicate biological equilibrium of nature, has kindled interest in the behaviour modifying chemicals. Sex pheromones because of their ecofriendly, chemically safe and efficacious nature have found increasing favour in pest management with the passing years and are considered as the "fourth generation pesticides".

Researches over the last two decades have augmented the number of pheromones following their role in insect communication and behavioural control, and pheromones of over 500 species of Lepidoptera have been identified and properties such as volatility, persistence, and stability have their basis on molecular structure and it is well known that smaller the molecules the more volatile the components. Different isomers can evoke very different behavioural patterns in a responsive insect and hence the discrimination between these molecules must occur in the antennae and in the central nervous system.

Pheromones function as attractants and disruptants and an optimal blend must be identified and appropriate formulations for their release should be developed with current technologies. Information on orientation of flying insects is through the study of wind tunnels and sensitivity of compounds through the Electroantennogram or EAG technique, wherein the antennae of freshly incised males are used and two steel or glass microelectrodes are inserted into the antennae to record amplitude and frequency of nerve impulses from the sensory cells. The development of gas chromatography in the mid fifties provided an ideal tool for handling relatively volatile stable compounds and the subsequent coupling of gas chromatography with mass spectrometry (GC-MS) has enabled identification with even nanogram units of material and computers with chemical libraries enable comparison of the compounds.

Communication Modality

The receptivity of the males or behaviour releasing effect on the part of the males depend on the sensitivity of the antennae which play a great part in chemoreception. Insects can detect a few hundred molecules of their sex pheromone in the environment with their antennae, which contain several hundred thousand receptor cells. The antenna is a well designed sieve for airborne molecules which filter the female attractant substances out of the air. In each of the two male antennae there are about 1,700 olfactory hairs in the silk moths sensitive to the pheromone and each hair is innervated by two sense cells.

Once lodged in the antenna the odour molecule passes through many microscopic pores, each olfactory hair with around 2,600 of these pores. The molecules diffuse through the pores to the microscopic tubules beneath them, which extend very close to the sensory cells. The odour molecules require only about five thousandths of a second to diffuse from the surface of the antenna to the sense cells and result in the triggering of the nerve signal. After pheromone binding they are transferred to specific receptor sites followed by signal transduction.

Effectiveness of insect pheromones is proverbial, with only a few molecules needed to produce a response effective at considerable distances. Signalling power of insect sex pheromones is seen from the fact that molecular concentrations of 100 m/ml of air is sufficient for attraction of males. A single moth releasing its pheromone downwind from a particular site will produce an "active air space" several kilometres long and over a hundred metres wide. Any male entering the active air space will then turn up-wind towards the females. Single complex chemicals have been known to elicit behavioural responses at lower concentrations as in cockroaches. Many moth species utilise specific blends of relatively simple fatty acid derived compounds. A unique enzyme has allowed moth species to produce a variety of unsaturated acetates, aldehydes and alcohols that can be combined in almost unlimited blends to impart species specificity. Some strains within species use different ratios of individual components within a blend.

To take the simple example of the queen bee substance, the pheromone 9-keto-2-decenoic acid attracts male drones to mate with the queen. As many as 32 compounds are identified from bees and the related 9-hydroxy-2-decenoic acid causes clustering and destabilisation of worker swarms. Similarly though it was believed that the only female pheromone of the cabbage looper appeared to be (Z)-7-dodecenyl acetate, more intensive have studies shown five other minor components of the female gland.

Biosynthesis takes place in the pheromonal gland, the starting point being an acetate that is converted into palmitic acid. Several species also use directly performed acids such as oleic, linoleic and linolenic acids. Interestingly enough in many insects peak gland titers occur before the release period, decrease during the release period, rising again during the non release period. In some instances like the danaiid butterflies and bark beetles, the pheromones come from the diet. Pyrolizzidine alkaloids in the diet produce danaidone, which provides the receptive female the needed signal in the selection of mates.

Transfer of these toxic alkaloids to females occur during mating, the female in turn incorporating the alkaloids into her eggs, to prevent predation. It is again this chemical communication that orchestrates the destructive mass attack of bark beetles. Several corn silk volatiles including the plant hormone ethylene could induce pheromone production in the corn earworm. Signals from the host plant volatiles cause release of Pheromone Biosynthesis Activating Neuropeptides (PBAN), which stimulate pheromone production.

As such presence or absence of surrounding vegetation also influences production and release of pheromones. While diurnal rhythms occur in many moths, in many others a higher titer is maintained in the gland at all times, periodical release following periodical transport to the gland's surface. In the overall communication system two aspects – the chemistry of signal transduction and the frequency with which the pheromonal components interact with the receptor cells of the antennae are significant. This frequency depends on the release rate of the signal chemicals and the plume structure that carries them to the receiving insects.

One of the mechanisms of disruption is that the pheromone artificially placed in the field produces plumes and male moths encountering them may respond to them as if they are coming from females flying upward, thus reducing mating rate. The correct blend and the abundance of pheromone molecules in a fluctuating plume are essential aspects mediating up-wind flight to the odour source. The receiving insects become receptive to the sex pheromones at a specific time when the emitting insect is 'calling', the fluctuating plume structure being an integral part of the signal. While the chemical gradient does not exactly attract a male, the correct blend and the abundance of pheromone molecules in a fluctuating plume are effective in modifying flight up-wind, so that the patterning of the pheromones is as important as their composition.

Pheromones in Insect Control

As for the practical use of pheromones in insect control they are used in estimating populations and to know the time of peak incidence with traps being set up baited with the attached pheromone. Trap designs have to be tailored to the function required, and the behaviour of insects as they approach the traps, enter or escape from them is important. Enough traps for all of a local population or of one sex could be used to break their life cycle.

Mating disruption is an equally efficient control method like radio-jamming in which a powerful interfering signal is broadcast. Spreading an attractant pheromone throughout the crop area should impair the ability of the insects to locate prospective mates that are emitting the same pheromone. In typical field applications the disrupting pheromone is dispersed either aerially or from dispensers scattered throughout the crop area. As many other insects are also attracted directly to the dispensers, the mating disruption strategy has been modified through use of an insecticide to the pheromone creating an 'attracticide'.

Not only does the high level of the pheromone in the field interfere with mate location, but also many insects are killed outright at the dispensers. Equally interesting is the 'cocktail approach' in which several pheromones are put together in one device. In general, the mechanisms involved in mating disruption relate to loss of sensitivity, unbalanced components of pheromones and camouflaging of odour trail of females.

Worldwide, a variety of crops like cotton, rice, sugarcane, vegetables are treated with pheromones for pests like boll worms and leaf caterpillar of cotton, stem borers of rice and sugarcane, and bark beetles in forests, and phenomenal success has been achieved with the pink boll worm of cotton The pheromone traps have to be fixed at different levels as the crops grow, the traps attracting moths up to two weeks. Most of the commercially used pheromones in insect control strategies are mono or di unsaturated aliphtic compounds possessing alcohol, acetate or labile aldehyde functional groups.

Examples of pheromone mixtures of well-known Indian insect pests showing synergism enabling increased sexual responses are listed below.

Table

Insects	**Pheromone mixture**
Agrotis ipsilon:	(Z)-11-dodecenyl acetate & (Z)-9,tetradecenyl acetate
Chilo suppressalis:	(Z)-11-hexadecenal & (Z)-13-octodecenal
Helicoverpa armigera:	(Z)-11-hexadecenal & (Z)-9-hexadecenal
Pectinophora gossypiella:	(Z,Z)-7,11-hexadecadienyl acetate & (E,Z)-7,11-hexadecadienyl acetate
Phthorimaea operculella:	(E,Z)-4,7-tridecadienyl acetate & (E,Z,Z)-4,7,10-tridectrienyl acetate
Plutella xylostella:	(Z)-11-hexadecenal & (Z)-11-hexadecenyl acetate
Spodoptera litura:	(Z,E)-9,11-tetradecadienyl acetate & (Z,E)-9,12-tetradecadienyl acetate

The quantity and quality of pheromones released depend on the attributes of the dispensers or lures, which can affect the longevity of the pheromone, release rate over time and stability of the pheromone. These along with the shape of the plume, control the active space within which male moths are activated and attracted to the source. The blend emitted by the dispenser should be analysed, since different compounds may be released at different rates.

Though extreme specificity of pheromones may be disadvantageous when the crop has more than one pest, the use of a blend of chemicals can be useful. With the potential advantage of pheromones over more conventional pesticides for regulating insect pests, there is a need for increased research in this area, especially where insecticide resistance has developed. With better technologies and increased understanding of the biological effects of pheromone compounds, notably behavioural diversity in the field, prospects of the use of pheromones in integrated pest management are really promising.

◆ Chapter 85

Antifeedants or Feeding Deterrents

Many chemical compounds have been in use serving to prevent the feeding of phytophagous and other insects without killing or repelling them. These have been termed the feeding deterrents or antifeedants. Isman *et al.* (1996) have preferred a more restrictive definition—"a behaviour-modifying substance that deters feeding through a direct action on peripheral sensilla (= taste organs) in insects".

Most of the secondary metabolites produced by plants in nature are defensive chemicals that discourage herbivory, either by deterring feeding and oviposition or by impairing larval growth, rather than killing insects outright. Antifeedant properties are found in the major classes of secondary metabolites viz., alkaloids, phenolics and terpenoids, the last class offering the greater number and diversity of antifeedants.

Triterpenoids have been well documented as insect antifeedants: limonoids, exemplified by azadirachtin, from neem (*Azadirachta indica*) and chinaberry (*Melia azadirach*); toosendanin and limonin from *Citrus* spp.; cardenolides, steroidal saponins and withanolides. The clerodanes and the abietanes of diterpenes are also well known antifeedants. The drimanes and the sesquiterpene lactones of sesquiterpenes are also potent antifeedants and include such as drimane polygodial from the foliage of water pepper (*Polygonum hydropiper*). Application of polygodial or methyl salicylate has been reported to reduce aphid population in wheat and increase the yield. Monoterpenes, which are major constituents of many plant "essential oils", also deter insect feeding.

The furnocoumarins and the neolignans constitute the anitfeedants among plant phenolics. Similarly, certain indoles and the solanaceous gycoalkaloids among alkaloids exhibit antifeedant activity. Antifeedants have also been recognised from plants *Cocculus trilobus*, *Clerodendron trichotomum* and *Lindera triloba*. Some potent insect antifeedants isolated from plants are listed in the table below:

Table Antifeedants isolated from plants

Chemical type	*Compound*	*Plant source*
Alkaloid (indole type)	Strychnine	*Strychnos nuxvomica*
Alkaloid (steroidal glycoside)	Tomatine	*Lycopersicon esculentum*
Diterpene (abietane type)	Abietic acid	*Pinus* sp.
Diterpene (clerodane type)	Ajugarin I	*Ajuga remota*
Monoterpene	Thymol	*Thymus vulgaris*
Phenolic (benzoate ester)	Methyl salicylate	*Gaultheria procumbens*
Phenolic (furanocoumarins)	Xanthotoxin (= 8-methoxy psoralen)	*Pastinaca sativa*
Phenolic (lignan)	Podophyllotoxin	*Podophyllum peltatum*
Sesquiterpene (drimane type)	Polygodial	*Polygonum hydropiper*
Sesquiterpene lactone (germacranolide type)	Glaucolide A	*Vernonia* sp.
Triterpene (cardenolide type)	Digitoxin	*Digitalis purpurea*
Triterpene (ergostane type)	Withanolid E	*Withania somnifera*
Triterpene (spirostane type)	Aginosid	*Allium porrum*

Apart from plant secondary metabolites some synthetic pesticides have been reported to have insect antifeedant activities. Synthetic pyrethroids are known to deter feeding of insects when applied at doses or concentrations below the causing any mortality. Application of the fungicide Bordeaux mixture is also known to deter insect feeding.

Compounds like Eulan CN and Mitin FF were in use for protection of fabrics against insects and their larvae. Others like chlorinated triphenylmethanes and triphenylsulfonium salts were also used in the case of phytophagous insects. A triazene compound was noticed to inhibit the feeding of some caterpillars. In addition to triazenes, other compounds are known, like the organotins, which are triphenyltin compounds to possess pronounced antifeedant activities. Triphenyl acetate was found effective against the potato tuber moth larvae and larvae of cutworms but its use has not been favoured due to environmental concerns. Carbamates or carbonic acid esters, known to have efficient insecticidal properties, are also known to have antifeedant properties, in particular the thiocarbamates and phenylcarbamates, which inhibit feeding by beetles. Pymetrozine, a recently introduced chemical with an unique mode of action, has been reported to interfere with feeding in sucking insects like whiteflies and aphids by blocking salivary flow required by them, thus leading to starvation.

As to the modes of action of antifeedants, they act as gustatory repellents, inhibiting the gustatory or taste receptors, that in turn send signals to the feeding center in the insect's central nervous system. In some the antifeedants are thought to block or otherwise interfere with the perception of feeding stimulants. It is also to be noted that insect feeding comprises three essential aspects-orientation on the plants, initial biting or feeding and sustained feeding. While the first two aspects are common to insects feeding on both antifeedant-treated and untreated plants; sustained feeding is absent in antifeedant-treated plants.

The advantages of using antifeedants appear to be their selective action, which do not affect parasitoids, predators or pollinators. Their toxic deposits have no adverse effects on honeybees and other pollinating insects. However, they have their limitations, in that only surface feeding insects are prevented from feeding and internal feeders and piercing and sucking insects are not affected. Dosage also appears to be high, compared to insecticides. One additional advantage that has been pointed out in using antifeedants from plants, has been that insects may turn from crops to weeds.

The disadvantages are that continuous exposure or repeated exposures to the antifeedant may cause the insect to become increasingly tolerant. It has been reported that caterpillars can become habituated to a variety of plant secondary metabolites and may become cross-habituated i.e., exposure to one antifeedant can render the insect less responsive to the other. This can be mitigated by mixtures of antifeedants.

The potential use of antifeedants depends on more creative and practical strategies. One aspect is combining a plant extract having antifeedant activity with an insect growth regulator and applying it for crop protection. Another strategy is the SDDS i.e., Stimulo-deterrent diversionary strategy, sometimes also referred to as "push-pull" strategy of Miller and Cowles (1990). In this the "push" is from the antifeedant applied to the crop needing protection and the "pull" constitutes an attractant applied to the adjacent trap crop or trap rows of the main crop.

Isman, M.B., *Pesticide Outlook*, August, 2002, 152–157.

Isman, M.B. *et al.*, 1996. *Recent Advances in Phytochemistry*, **30:** 157–178.

Miller, J.R. and R.S. Cowles. 1990. *Journal of Chemical Ecology*, **16:** 3197–3212.

◆ Chapter 86

Insect Repellents

Insect repellents are chemicals causing insects to move away from their source and have been defined as “substances whose stimuli elicit avoiding reactions.” They are not to be confused with antifeedants, since their action is to cause directed movements away from the source. They are typically behavioural responses arising through the stimulation of chemoreceptors, olfactory or gustatory receptors. Physical repellents are still used such as water barriers, tar or oil bands around tree trunks. Several chemical repellents, natural and synthetic are available today. Oil of citronella and oil of camphor are widely used as mosquito repellents. Spraying of Bordeaux mixture comprising copper sulphate and lime repels leaf hoppers and some chewing insects. Chemical treatment of logs keep them away from borer attack. Since the last world war several synthetic repellents have been discovered against body lice, mosquitoes, fleas, houseflies, ticks and chiggers. Of these dimethyl phthalate has proved effective in skin applications and benzyl benzoate and dibutyl phthalate for treatment of clothing. Diethyl toluamide is a product, which also provides protection against mosquitoes, ticks and fleas. Other cosmetically acceptable repellents in the form of cream or lotions are that of diethyl toluamide.

Buildings are protected against termites by the use of trichlorobenzene and similarly ants are repelled by ant tapes containing bichloride of mercury. Creosote and coal tar protect wood from termite attack and repel chinch bug migration. Butyl polypyrphene and dibutyl succinate are suitable repellents for application to live stock. Pyrethrum in low concentrations repels blood-sucking insects and are, therefore, used in cattle sprays. Application of pine tar oil and diphenylamine repels the screw worm flies from laying eggs around the wounds of animals. Recently effective compounds have been formulated for use against a wide range of insects attacking man and these compounds are related to cyano-acetic derivatives.

◆ Chapter 87

Sterility Methods of Pest Control

Inducing sexual sterility through the utilisation of radioactive isotopes, in large populations of insects, has been successfully employed in recent years in the control of some pests such as the screw worm in the USA, the oriental fruit-fly, and more recently mosquitoes. The procedure involves mass rearing, sterilisation and release of several thousands of males which compete against their own kind for reproduction. In course of time, after repeated releases, the sterile males would outnumber the normal males and the final outcome would be the disappearance of natural populations subjected to such treatment. The pioneering work of Knipling in this direction has led to effective control of the screw worm (*Cochliomyia hominivorax*), the melonfty (*Bactrocera cucurbitae*), the Oriental fruitfly (*B. dorsalis*), the Mediterranean fruit fly (*Ceratitis capitata*), etc. Introduction of fully competitive sterile individuals in a population reduces the reproductive potential of the natural populations. Initially, however, only males were sterilised to eradicate isolated population, but subsequently the sterilisation of a given proportion of both sexes of the natural population was found to be equally useful. Sterilisation of 90 % of an insect population has been estimated to reduce the reproductive capacity of the remaining 10 % by 90 %, leaving only 1 % to reproduce, the net result being the suppression of their reproductive capacity by 99 %.

The sensitivity of insects to radiation is low when compared to that of vertebrates and it also varies with the age of the insect. Quite a few differences exist between the sterilising dose and the lethal dose for the different postembryonic stages of insects. This radioresistance of insects has been attributed to the meagre cell division and differentiation of tissues occurring in the larval life, where growth takes place through increase in cell volume without a corresponding increase in cell numbers. Since the mitosis is seen in the pupal stage, this stage is radiosensitive, and in the adult the cells of the gonad divide which are sensitive to radiation. Here even low doses result in sterilisation, without damaging other tissues. The sterility dose for a medium-sized insect is about 5,000 to 8,000 and the lethal dose 200,000r.

Insects are irradiated by exposure to Cobalt 69 irradiation, where large populations could be handled. Radioactive isotopes are also applied on insects by spraying the insects with a solution on a particular area of the body or by feeding the insects on diets containing the isotope. This method also serves in the identification of the treated insects by their radioactivity. The common radioactive isotopes used for labelling studies with insects are carbon 14, phosphorus 32, iodine 131, bromine 82, arsenic 76, sulphur 35, etc.

When the extension of sterility techniques to other insects is considered, several aspects have to be looked into, especially the effect on survival and reproductive behaviour, methods to be adopted for rearing and proper methods of dispersal of released sterile insects so that they could mix with natural populations. Further, the sterile insects should also not cause undue loss to crops and livestock. Through repeated release of sterile males, the ratio of sterile males to normal males becomes increased.

Sterility method has been employed more recently in fighting the gypsy moth, codling moth, cotton bollworm and weevil, *Anopheles* sp., and it seems that the technique will attract more attention.

◆ Chapter 88

Plant Quarantine

The term 'Quarantine' is derived from the latin word '*quarantum*' meaning forty. It was originally applied to the period of detention of ships arriving from countries where epidemics like bubonic plague, cholera and yellow fever occur. The passengers and crew were to remain isolated on board giving enough time to permit latent cases of diseases to develop. When compared to human quarantine , plant quarantine is a later development. The first Plant Quarantine legislation in the world was enacted in the Netherlands. East Indies (Indonesia) in 1877 prohibiting the importation of coffee plants and seeds from Sri Lanka. India adopted plant quarantine measures in 1914 by introducing the Destructive Insects and Pests Act. This was later supplemented by a more comprehensive statute in 1917.

Plant quarantine is a legislative measure to prevent or to exclude from a defined geographical area a serious pest or disease of plants exotic to that particular geographical area.

In order to improve agricultural production or to supplement the food needs, plants, plant material and plant products are in continuous transport from one region to another. Germplasm banks have been established for important crops in different parts of the world. Exchange of germplasm material among nations has become a regular feature.

Some of the flora and fauna are specific to certain geographic regions. When man moves plants, seeds, timber or even goods, he is also likely to move an insect or fungus from its native habitat. Such an introduced pest may behave entirely different from its native habitat. Freed from its natural enemies and competitors and with availability of possible susceptible host/s in its new environment, the pest species may have more serious effects than in its place of origin. Consequently, in order to prevent such introduction and safeguard agriculture, horticulture, forestry, and human and animal health, Governments have come up with legislative measures.

There are instances in Indian history to show that some introduced pests were disastrous. The coffee berry borer *Hypothenemus hampei,* the San Jose scale *Quadraspidiotus perniciosus,* the apple woolly aphis *Erisoma lanigera,* and the Spiralling whitefly *Aleurodicus dispersus* are some examples.

In India two categories of regulatory measures are in operation to prevent entry of foreign pests and to prevent spread of already established pests. They are:

- Legislative measures through Plant Quarantine, and
- Legislative measures through State Agricultural Pests and Diseases Act.
- In the first category, regulatory measures are aimed at preventing the introduction of exotic pests and diseases into the country from abroad or their spread from one State or Union Territory to another; while the second pertains to suppression or prevention of spread of pests and diseases in localised areas within a State or Union Territory.

In line with other countries, India has also developed facilities for plant quarantine inspection and treatments at the seaports of Mumbai, Kolkatta, Kochi, Chennai, Tuticorin, Rameswaram, Bhavnagar and Vishakapatnam, and at the airports of Amritsar, Chennai, Kolkatta, Mumbai, New Delhi and Tiruchirapalli. The land-frontiers are Attari-Wagah border, Amritsar district and Bongaon, Gade Road, Kalimpong and Sukhiapokri in West Bengal. These stations operate under the Government of India's Destructive Insects and Pests Act, 1914. The importation of consignments of plants from foreign countries has to be done only through any of these ports. The consignments should be accompanied by certificates issued by the authorities of the exporting country as to their freedom from pests and diseases; these certificates are called phytosanitary certificates. At the port of entry these consignments are inspected, and if necessary, fumigated to kill the pests carried by them. Detention of consignments is ordered if found infested/infected with a quarantine pest or imported in contravention with plant quarantine regulations, for arranging deportation, failing which the consignments shall be destroyed at the cost of the importer.

In a similar way, all exports of commodities such as pepper, tamarind, cardamom, mango, tissue culture plant material, flowers, etc. are required to have phytosanitary certificates accompanied with the consignments.

The Directorate of Plant Protection, Quarantine and Storage was established in 1946. Prior to this the enforcement of quarantine laws and disinfestations of plants as laid down in the Act was done by customs authorities. From 1949 the Directorate has established quarantine stations in a number of ports and airports and land frontiers, and is in charge of these activities.

In the case of importation of natural enemies from other countries into India for being used in the biological control of weeds, prior permission to import such natural enemies is granted by the Plant Protection Adviser to the Government of India and quarantined at the Project Directorate of Biological Control, Bangalore and evaluated. After it is satisfactorily established that the introduced species is not likely to become a pest species, further developments in the fields and other laboratories are taken up. When live insects are sent abroad, a no objection certificate that the species is not covered under endangered species must be obtained for clearance for export. Further a no objection certificate from the importing country should also be annexed to the consignment to meet the quarantine requirements of the importing country.

Section Ten

Toxicology

◆ Chapter 89

Insecticides and Their Classification

The term ***pesticide*** is used to denote those chemicals, which poison and control the animal and plant species. Many chemicals are used for reducing the population of insects or for preventing their attack. Chemicals, which kill insects by their chemical action, are called insecticides. ***Insecticide*** is thus defined "as a substance or mixture of substances intended for killing, repelling or otherwise preventing insects." Likewise chemical substances applied to kill nematodes, mites, rats and molluscs are referred to respectively, as nematicides, acaricides, rodenticides and molluscicides. A chemical may be called a repellent if it prevents the pest species from attacking its host and an attractant if the pest species is attracted to the source, trapped and killed. If the chemical applied inhibits feeding it is called an antifeedant. Chemicals, which induce sterility are grouped as chemosterilants. Biorational pesticides are those which include pest control agents and chemical analogues of naturally occurring biochemicals, viruses, bacteria, protozoans and fungi, and thus distinct from chemical pesticides.

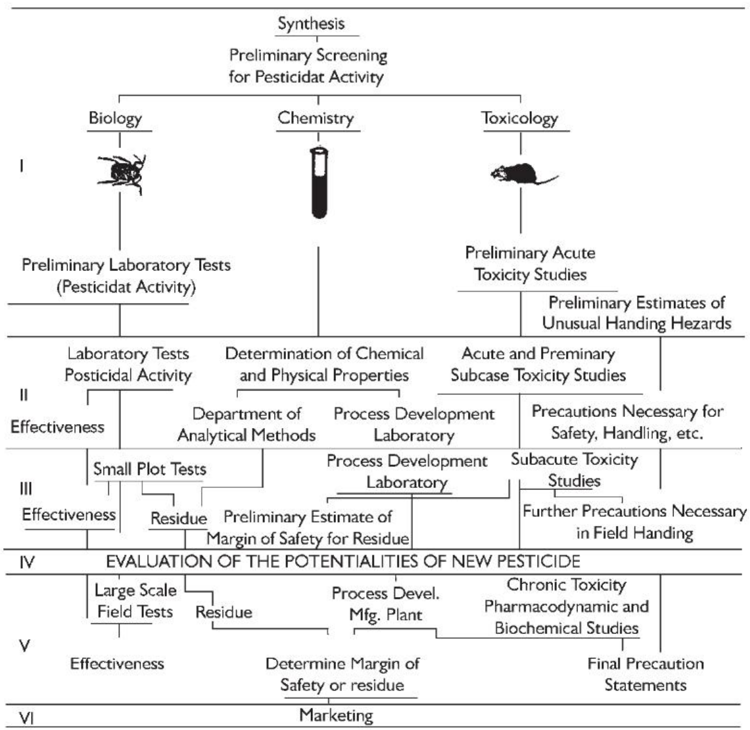
I. HISTORICAL BACKGROUND OF THE USE OF PESTICIDES

Insecticides were in use from very early times and as early as 200 BC boiling a mixture of bitumen (mineral pitch or asphalt) and blowing the fumes through grape leaves was advocated to keep away the insects. Sulphur was considered to be injurious to insects in 100 BC. The toxic nature of arsenic was known about 40 to 90 AD and arsenic sulphide was used by the Chinese before 900 AD. Arsenic in honey was suggested as an ant bait since 1669. The use of tobacco in the control of the lace bug on pear trees was in vogue in 1690. Pyrethrum was widely used before 1800 in Persia.

The use of modern insecticides commenced in 1867 with the application of Paris Green for the control of the Colorado beetle. Mostly organic chemicals and a few plant products were in use until 1939 when the whole concept of insecticides and of insect control was revolutionised with the discovery of the insecticidal spectrum of DDT. Since then a large number of compounds have been synthesised, examined for their insecticidal activities and developed. In 1941-42 the insecticidal properties of HCH were discovered by British and French investigators. During the same period the potential of phosphorus chemicals were investigated by the Germans, which led to the development of parathion, malathion, demeton, TEPP, etc. Since then phenomenal progress has been made in the development of insecticides, as a result of which insecticides have now been found among organophosphates, carbamates and other new classes of compounds.

II. PESTICIDE RESEARCH AND DEVELOPMENT

About 20 large companies in Western Europe and the USA are actively engaged in basic discovery, development, evaluation and manufacture of modern pesticides. The six stages involved in the development of a new pesticide from synthesis to marketing are illustrated in Fig. 88.1.



▲ **Fig. 89.1** *The six stages in the development of a new pesticide*

Primary screening, determination of general biological characteristics, analytical and metabolic studies, basic and applied toxicology, chemical synthesis, formulation studies, etc. are undertaken in a single location and duplication of such investigations in some other locations is unnecessary. On the other hand the evaluation of biological performance and assessment of possible hazards under the intended conditions of use require to be studied in different locations, which may involve investigations against locally important pests and under local climatic and agricultural conditions. The basic chemical discoverer, by his own network of centres in different countries or in cooperation with other distributing companies, carries out extensive field investigations as part of the development work. The success of a compound largely depends on its safety, efficacy and profitability to the user.

It takes about five or occasionally more years for the development of a compound and it has been estimated that around one in 360,000 of the compounds become a major commercially successful new pesticide. Around six to ten million US dollars are spent in the development of a major new insecticide and this brings out the high expenditure involved on research and development of a pesticide.

III. INSECTICIDE FORMULATIONS

It is essential that the toxicant must be amenable to application in an effective manner so as to come into direct contact with the pest or leave an uniform and persistent deposit upon the plant surface. Only a small quantity of the toxicant is required to be distributed over a large area and very rarely the toxicant in a concentrated form, suitable for direct application, is formulated. The toxicant is to be made available in a diluted form or in a form easily distributed. Therefore, the compound containing the toxicant must be formulated in a form suitable for use as a spray, dust or fumigant. The common formulations of pesticides are detailed hereunder.

1. DUSTS

In a dust formulation the toxicant is diluted either by mixing with or by impregnation on a suitable finely divided carrier. The carrier may be an organic flour (Walnut-shell flour, wood bark) or pulverised mineral (sulphur, diatomite, tripolite, lime, gypsum, talc, pyrophyllite) or clay (attapulgite, bentonites, kaolins, volcanic ash). The toxicant in a dust formulation ranges from 0.65 to 25 %. Dusts are defined as those having a particle size less than 100 microns and with decrease in particle size the toxicity of the formulation increases. The properties of the diluents employed mainly decide the quality of the finished dust formulation and the rate of decomposition is influenced by the kind of diluents. Some formulations are inactivated by alkali. In the selection of a dust formulation its compatibility, fineness, bulk density, flux, abrasiveness, absorbability, specific gravity, and cost must be borne in mind. The dust should flow freely and must not cake or ball in the hopper. It has been reported that in field application deposition had been more on the undersurface of leaves and in those held parallel to the air-stream carrying the dust. Dust application must be done in calm weather conditions and early in the morning when the plant is wet with dew.

2. GRANULAR OR PELLETED INSECTICIDES

In a granular formulation the particle is composed of a base such as an inert material or vegetable carrier impregnated or fused with the toxicant, which is released from the formulation in its intact form or as it disintegrates giving controlled release. The particles in the formulations generally possess a size range of 0.25 mm to 2.38 mm diameter but usually 250 to 1250 microns. Those having a range of 100 to 300 microns are referred to as a microgranules, and those above 300 microns as granules. The formulations contain two to ten per cent concentration of the toxicant. This type of formulations finds use in the control of weeds, plant diseases and insect pests, nematodes, snails, rodents, etc. Granules are prepared in three ways:

(i) Spray impregnation technique in which a solution of the toxicant or, if liquid, the toxicant itself is sprayed on to preformed absorptive granules.

(ii) Agglomeration technique in which the toxicant and powdered filler, together with any other additives, are moistened with water or other suitable liquid and formed into granule and dried. In this method, there is considerable degree of control over the release of the toxicant.

(iii) Stick-on technique in which the toxicant is applied as a thick, viscous slurry so as to stick to the outside of the impregnable granular base such as sand. Adsorptive clay is then added to the formulation or it is dried to remove any surplus liquid and prevent the finished granules from sticking together. This method allows least control over the release of the toxicant.

The granules are applied over standing water or whorls of plants or to soil. In the water the toxicant from the granule is released to act in three ways: by vapour, by systemic action through plant roots, and systemically in the leaves and stem. When applied on the soil or incorporated into it by tilling or by drilling or by hand there is increased retention. When applied to foliage retention of the granule in leaf axils and its breakdown assisted by moisture are important. The toxicant and granule particles are picked up directly by mobile insects and systemic toxicants enter the plant.

The performance of granules is dependent on uniformity of distribution, weather factors particularly duration and intensity of rainfall and temperature, concentration, dosage rate of the toxicant, etc. Granular formulations of systemic insecticides are used for the control of sucking and soil pests by application to the soil. Whorl application is done for the control of borer pests of crops such as sorghum, maize, sugarcane etc.

The stability of *Bacillus thuringiensis israelensis,* if not protected in a suitable formulation, is considerably restricted as a result of UV light action and biological degradation. A new time release granular formulation has been developed providing more sustained release and increased UV protection of the active ingredient.

Advantages of granules are:

(i) There is very little drift,

(ii) There is no undue loss of insecticide,

(iii) Undesirable contamination is prevented,

(iv) Residue problem is considerably less as granules do not adhere to plant surface,

(v) Release of toxic material is achieved over a longer period than does a spray deposit,

(vi) Water is not required for application.

(vii) Less harmful to natural enemies of the pest species,

(viii) Ready to use; no mixing, is required

(ix) Low hazard to applicator.

Disadvantages of granules are:

(i) Not as effective as sprays against most crawling insects,

(ii) Scorching may occur if the toxicant is concentrated in a smaller volume of carrier,

(iii) Won't adhere to foliage,

(iv) More expensive than WPs and ECs.

(v) May need to be incorporated into soil in some cases,

(vi) May need moisture to activate pesticidal action.

3. WETTABLE POWDER (WP) OR WATER DISPERSIBLE POWDER (WDP)

It is a powder formulation, which yields a rather stable suspension when diluted with water. The active ingredient in such a formulation ranges from 15 to 95 per cent. It is formulated by blending the toxicant with a diluent such as attapulgite, a surface-active agent and an auxiliary material (such as sodium salts of sulfo acids obtained by sulfonation of petroleum products, sodium salts of lignin sulfo acids). Sometimes stickers are added to improve retention on plants and other surfaces. Though the particles of a suspension adhere well to treated surfaces they do not penetrate and thus are easily washed off. However, suspensions are usually more effective than dusts. The requirements for a water dispersible powder formulation are:

(a) Stability in storage and absence of caking;

(b) Quick formation of suspension and slow settling out of solid particles;

(c) Good moisture retention capacity and ability to spread over treated surface: and

(d) Retention on treated surface for a longer period.

4. WATER SOLUBLE POWDER (SP OR WSP)

The water soluble powders contain an active ingredient in the form of surfactants with special additives. It is a powder formulation readily soluble in water. Addition of surfactants improves the wetting power of the spray fluid. Sometimes an anti-caking agent is added, which prevents formation of lumps in storage. This formulation usually contains a high concentration of active ingredient and, is therefore, convenient to store and transport. Carbaryl 85 SP and Acephate 75 SP are registered in India.

5. LIQUIDS

Many of the synthetic organic insecticides are water insoluble but soluble in organic solvents such as amyl acetate, carbon tetrachloride, ethylene dichloride, kerosene, xylene, petroleum naphtha, pine oil, etc. which themselves possess some insecticidal properties of their own. Solvency, toxicity to plants, fire hazard, compatibility, odour and cost are factors to be considered in the selection of a suitable solvent. Some toxicants are dissolved in an organic solvent and used directly for control of household pests and other aquatic insects especially mosquitoes.

5.1 Emulsifiable Concentrate (EC)

The formulation contains the toxicant, a solvent for the toxicant and an emulsifying agent. It is a clear solution and yields an emulsion of oil-in-water type when diluted with water to spray strength. When sprayed the solvent evaporates quickly leaving a deposit of toxicant from which water also evaporates. Some of the emulsifying agents in insecticide formulations are alkaline soaps, organic amines, sulfates of long-chain alcohols, sulfonated aliphatic esters and amides, and materials such as alginates, carbohydrates, gums, lipids, proteins and saponins. The addition of emulsifying agents have the following specific purposes in insecticidal formulations:

(i) Diluting of a water insoluble chemical with water is made possible;

(ii) The surface tension of the spray is reduced allowing it to spread and wet the treated surface;

(iii) A better contact with insect cuticle is made possible;

(iv) Droplet size of the emulsion is greatly influenced by the kind and amount of emulsifier used;

(v) The chemical structure of the emulsifier has influence on the stability and behaviour of the emulsion. Emulsions are not stable and tend to separate into component parts and this is referred to as "breaking". The amount of emulsifier and agitation applied to the emulsion control this phenomenon to some extent. A fairly quick-breaking emulsion is preferred in crop spraying in view of heavier deposits of toxicant obtainable probably due to limited run off. An emulsion may separate into two phases due to differences in specific gravity of the components and this partial separation of the emulsion known as "creaming". The emulsion can be returned to homogenous condition by slight agitation.

5.2 Suspension Concentrate or Flowable (F)

The suspension concentrate consists of an active ingredient, water, surfactants(wetting agents, dispersing agents), special additives and carrier. When an active ingredient is insoluble in either water or organic solvents, a flowable formulation (F) is developed. The active ingredient is milled with a solid carrier (e.g. inert clay) and subsequently dispersed in a small quantity of water. It can easily be measured and poured and hence easy to handle. Prior to application it has to be diluted with water. Flowables may show sedimentation of the solid materials in storage and agitation by stirring or shaking makes the sediment redispersed. A flowable formulation of carbaryl was considered safer to honeybees and exhibited rain fastness.

5.3 Solution Concentrate (SC)

The solution concentrate of active ingredient, water immiscible solvent and surfactants. This liquid formulation contains the active ingredient in a water miscible solvent. When mixed with water during spraying the solvent dissolves in water leaving the a.i. (active ingredients) alone. Addition of a surfactant provides wetting power. Example: monocrotophos.

5.4 Concentrate Insecticide Liquids

The technical grade of the toxicant at a high concentration is dissolved in non-volatile solvents. A more volatile solvent is also added to enable solution and drop formation. An emulsifier is not added. The solvent used should not be phytotoxic. Concentrate insecticide liquids should be non-volatile, and have a high viscocity and high specific gravity (over 1.3 g/ml). This condition enables it to be applied from higher altitudes in extremely fine droplets without being diluted with water and at ultra volume rates. There is greater residual toxicity and less loss through evaporation on application and extensive coverage is achieved. Concentrate liquid formulations of malathion and fenitrothion have been permitted to be used in India.

6. MICROENCAPSULATION

Microencapsulation process involves particles of a pesticide, either liquid or dry, surrounded by a plastic coating. This is mixed with water and applied as a spray. Encapsulation makes timed release possible.

7. AEROSOLS

In insecticide aerosol the toxicant is suspended as minute particles (of size ranging from 0.1 to 50 microns) in air as a fog or mist. This is achieved by burning the toxicant or vapourising it with heat or atomising mechanically. The toxicant dissolved in a liquefied gas, if released through a small hole, may cause the toxicant particles to float in air with the rapid evaporation of the released gas.

8. TABLET

Deltamethrin has been formulated in the form of tablet, which readily dissolves in water; when a tablet is mixed with 20 litres water to cover 400 sq. m. crop area it gives 12.5 g a.i./ha dosage. Aluminium phosphide, magnesium phosphide and boric acid are also formulated in tablet forms.

9. PLATE/STRIPS

The fumigant Magnesium phosphide is available in the form of strips or plates.

10. MIXTURES OF ACTIVE SUBSTANCES OR PRE-MIXES OR COMBINATION PRODUCTS

It becomes necessary often to apply mixtures of active substances of insecticides for obtaining effective control of the pest complex in a crop. The following four types of action for mixtures of active substances are recognised.

(a) Similar action: The two components in a mixture act independently but produce similar effects whether they are applied as a mixture or alone. For example, one may have quick acting property and another residual toxicity.

(b) Independent action: The two components are different and independent in action i.e. no synergistic effect. For example, parathion methyl and 1% sesamex, a pyrethrum synergist against housefly.

(c) Synergistic action: The toxicity of the mixture is greater than that of the sum of the individual components. This phenomenon is referred to as synergism or activation. For example, 1% of the pyrethrum synergist sesamex acts synergistically with phosphates containing amino or amido groups. Piperonyl butoxide, piperonyl cyclonene, N-isobutyl undecylenamide, propyl isome, sesoxane, etc. are some insecticide synergists.

(d) Antagonistic action: One component in a mixture reduces the activity of the other in the mixture. For example, due to antagonistic action the toxicity of thionophosphates is diminished by sesamex; antagonistic action between aldrin and parathion. Combination products or pre-mixes are products constituted by mixing two or more compatible pesticide molecules in the right concentration. This concept in not very novel as farmers have been mixing pesticide in a tank i.e. tank mix before application. Where as individual components of the combination are effective only against specific pests, pre-mixes are effective over a broad spectrum of pests. The pre-mix is formulated under controlled conditions and the constituents are decided so as to attain synergy out of their joint action. The compatibility of the constituents is gauged and the effect of the cross-interaction of various auxiliaries is analyzed for any hazardous side effects. It is feared that if any pest species develops any resistance against any mixture then the resistance problem will be more cumbersome because of cross-resistance.

The following combination products have been registered for use in India: Cypermethrin 50 g + chlorpyrifos 500 g/ litre, Cypermethrin 40 g + profenofos 400 g/ litre, Cypermethrin 30 g + quinalphos 200 g/litre, Carbaryl 40 g + gamma HCH 40 g/kg granule, Cyperme-thrin 50 g + chlorpyrifos 500 g / litre, Cypermethrin 50 g + ethion 400 g / litre, Deltame-thrin 10 g + triazophos 450 g / litre, and Alphacypermethrin 10 g + chlorpyrifos 160 g / litre.

The advantages of mixtures of active substances of insecticides are:

(i) Effective pest control as well as reduction in cost of control operation is achieved,

(ii) Development of resistance in insects to insecticides may be prevented due to independent action of the active substances in the mixtures,

(iii) It is also possible to control resistant strains of insects.

11. POISON BAITS

The poison baits consist of a base or carrier material attractive to the pest species and a photogenous or chemical toxicant in relatively small quantities. The poison baits are used for the control of fruit-flies, chewing insects, wire-worms and white grubs in the soil, household pests, and slugs. This method is ideal under conditions where spray application is rather difficult. The common base used in dry baits is wheat bran moistened with water and molasses as an attractant, and a toxicant such as parathion, sodium arsenite, etc., is added. Ground corn cobs, hulls of seeds, saw dust, horse droppings etc. are also used as base. Amyl acetate, chopped whole orange or other fruits, etc., are also used as attractants. Such baits are adopted for the control of locusts, grasshoppers, cutworms, armyworms, cockroaches, crickets, earwigs, silverfish, etc. Poison baits in liquid bases are used for control of fruit-flies, fruit-piercing moths, houseflies, ants, etc. The baits for fruit-flies usually consist of methyl eugenol + DDVP or malathion with corn protein or yeast hydrolysate. For the control of fruit-piercing moths fermenting sugar solution or molasses with a toxicant is used. Cockroaches and houseflies are killed by the use of baits containing a toxicant, attractants and auxiliaries. For successful poison baiting the attractivity, palatibility, toxicity, stability and physical condition of the baits as also the time, place and method of exposure must be considered. Difficulty in achieving an uniform spread of the bait throughout the crop, high cost of the attractants, and non-persistence for a longer period are some limiting factors in successful poison baiting in pest control.

12. FUMIGANTS

A chemical compound, which is volatile at ordinary temperatures and sufficiently toxic, is known as a fumigant. Fumigants are used for the control of insect pests in storage bins, buildings and ship holds, and certain insects and nematodes in the soil. It is practicable under situations where the gas can be confined. Most fumigants are liquids held in cans or tanks and quite often they are mixtures of two or more gases. Phosphine or hydrogen phosphide gas is generated in the presence of moisture from a tablet/strip/plate consisting of aluminium or magnesium phosphide and ammonium carbamate. Sometimes the gas is required to be produced at the site of fumigation as in hydrogen cyanide, which is by dropping calcium cyanide into earthenware crocks filled with sulphuric acid. The advantage of using a fumigant is that the places not easily accessible to other chemicals can be easily reached due to the penetration and dispersal effect of the gas. However, the fumigants should be handled with utmost care as the gas may prove to be toxic or may cause flavours in the treated crop.

13. SPECIAL FORMULATIONS

These are prepared for specific purposes. In oral administration of insecticides in animals they are prepared as boluses (large pills) or capsules with a balling gum. In the treatment of pet animals in houses the insecticide may be mixed in shampoos. Sometimes an insecticide may be mixed with wax and applied on floors. Extremely toxic systemic insecticides are prepared at the factory in gelatine capsules. When gelatine gradually breaks down in the soil toxicant enters the soil and gets absorbed by the plant roots.

14. INSECTICIDE-FERTILIZER MIXTURE

The mixtures generally constitute addition of a granular insecticide to chemical fertiliser or spreading of insecticide directly on to the fertiliser. They are applied at the regular fertilizing time and provide both plant nutrients and control of soil insects. Urea 2% solution is mixed with compatible insecticidal emulsions and sprayed for supply of nitrogen to the plant and for realising effective pest control. Many pesticides are rapidly broken down when mixed with fertilisers.

15. ADJUVANTS IN INSECTICIDE FORMULATIONS

Deodorants and Masking Agents

Addition of pine oil, flower scent, etc. at 0.1 to 1.0 % concentration to finished products of insecticides is done to mask the unpleasant odours of insecticidal components such as pyrethrins, thiocyanates and methylated naphthalenes.

Stabilising Agents

These are added to relatively unstable organic insecticides to retard decomposition in storage. Decomposition of pyrethrin in louse powder is prevented by mixing of an antioxidant mixed isopropyl cresols. Epichlorohydrin, an acid inhibitor, prevents the dehydrochlorination of aldrin and toxaphene formulations. Organochlorine insecticides are stored in metal drums provided with special interior lacquer linings to prevent decomposition.

Spreaders

These are auxiliary spray materials, which directly facilitate contact between spray (liquid) and sprayed (solid) surfaces. The spreader in insecticidal formulations has three important functions viz. wetting, spreading and penetrating effects. Soaps, alkyl sulphates or sulphated alcohols are available under different trade names. Secondary alcohol sulphates from petroleum oil refinement such as Teepol, Tergitols, etc., fatty acid detergents such as Mersolates, etc., Triton X-100, Tweens, and a few other non-synthetic products such as saponins from wide variety of plants, particularly from the bark of *Quillaja saponaria* and the pericarp of the fruit of *Sapindus utilis*, are some spray spreaders.

Stickers in Insecticides

The adhesiveness of certain formulations of insecticides, such as emulsions and wettable powders, is improved by addition of stickers or supplementary adhesive materials like various clays and bentonites, soybean flour, casein, gelatin, petroleum and vegetable oils, blood albumin, etc.

16. WATER-SOLUBLE PACKET

It is used to reduce the mixing and handling hazards of some highly toxic pesticides. Known quantity of wettable/soluble powder formulation is packaged in water-soluble plastic bags. When the bag is dropped into a filled spray tank it dissolves and releases the content to mix with the water. There is no risk of inhaling or coming into contact with the undiluted pesticide during mixing as long as the packet is not opened.

IV. CLASSIFICATION OF INSECTICIDES

Insecticides may be classified in several ways based on the mode of entry, mode of action, and the chemical nature of the toxicant or active ingredient.

1. CLASSIFICATION BASED ON MODE OF ENTRY

Based on the manner in which toxicants arc administered to the insects and their mode of entry into the body, the insecticides are classified into three groups–stomach poison, contact poison and fumigant.

Stomach Poison

These include those toxicants applied to the food. When ingested by the insect, the insecticide kills primarily by action on or absorption from the digestive system. Though usually it is limited to the control of insects with chewing mouthparts, under certain conditions it may also find use in controlling insects with sucking, siphoning, sponging or lapping type of mouthparts.

The possible ways of ingestion of the stomach poisons are:

(i) The insect while feeding on its natural food, such as foliage, feathers of birds, etc., covered thoroughly with the toxicant, ingests the poison also;

(ii) By feeding on poison baits consisting of the toxicant and an attractant in a suitable food material;

(iii) The toxicant sprinkled on runways is picked by the antennae and legs of the insect and it is likely to ingest the poison while cleaning these appendages with its mouthparts; and

(iv) Sucking insects, while feeding on plants treated with systemic insecticide, suck the plant sap containing the toxicant, which acts as a stomach poison in the insect.

A stomach poison should be sufficiently stable, cheap and available in larger quantities and should not be distasteful as to repel the insect. It should be able to kill the pest quickly. The chemical should not be soluble in water and phytotoxic to plants, it should have finer particles and spread uniformly and adhere well to the treated surface, it should not leave any harmful residue on the treated surface.

Contact Poison

A toxicant, which kills the insect by contact and whose entry into the body is through the vulnerable sites found on the body of insect is said to be a contact poison. It may be applied directly on to the body of the insect as spray or dust. On the other hand if application is made so as to leave a residue of the toxicant on plant surfaces, animals, habitations, etc. frequented by insects, the toxicant is likely to be picked up by the insect when it comes in contact while crawling or passing over the treated area. This type of poison is particularly effective for the control of sucking insects.

When applied, the toxicant spreads quickly over the entire surface of the body of the insect, possibly in the wax monolayer and apparently from there, the poison gets absorbed on to the surface of the cuticle. It penetrates into the body of the insect through sutures, membranes, bases of setae and possibly other portals of entry. Though it was widely held that the insecticide penetrates through the integument of the body wall and gets carried to the target organ, the central nervous system by the haemolymph, investigations have shown that the toxicant does not penetrate into the haemolymph in significant amounts and reaches the site of action via the integument of the tracheal system.

Contact insecticides are found in:

(a) toxicants of plant origin such as rotenone, nicotine, anabasine, ryania, sabadilla and pyrethrum:

(b) synthetic organic compounds such as organochlorines, organic thiocyanates, organophosphates, carbamates, nitrophenols, etc.;

(c) oils and soaps and

(d) inorganic compounds such as lime-sulphur and sulphur, and arsenic trioxide and sodium flouride to a limited extent.

Many contact insecticides at higher dosage levels may prove to be phytotoxic on plants.

Fumigant

A toxicant which is applied as a vapour, enters the tracheae of the insect through the spiracles in the form of gas and kills the insects; such gaseous toxicant is called a fumigant. Fumigants finds use in the control of all kinds of insects irrespective of the type of mouthparts they possess. Their application is limited to plants or products in air-tight enclosures, tents or buildings or to soil. A fumigant, which generally boils at about room temperature is the most useful one and such chemicals include methyl bromide, hydrogen cyanide and ethylene oxide. The essential requirement of a soil fumigant is slower release of vapour from chemicals boiling at a temperature as high as 180°C. Fumigant action is evidenced when naphthalene and paradichlorobenzene having relatively high vapour pressure are used in tight containers, and also in certain contact insecticides like DDVP, lindane, etc. An ideal fumigant is determined by its relative effectiveness, cost, safety to human beings, animals and plants, inflammability, penetrating power, effect on germination of seeds, reactivity with household furnishings, etc.

2. CLASSIFICATION BASED ON MODE OF ACTION

Based on the ways in which the chemicals act upon the system of an insect to cause its death, insecticides may be classified as follows:

Physical Poison

A physical poison exerts a physical rather than a biochemical effect and brings about destruction of insects by asphyxial (exclusion of air) effect as with heavy oils and tar oils, or by effecting a loss of body moisture from the insect by inert dusts. Epicuticle of the insect gets lacerated by abrasive dusts like aluminium oxide, flyash etc., and this may cause water loss. Water absorbent materials like charcoal remove water. Certain dusts may combine both the characteristics.

Protoplasmic Poison

A protoplasmic poison is primarily associated with precipitation of protein. The cellular protoplasm of midgut epithelium is destroyed by inorganic stomach poisons like fluorides, arsenites, arsenates, fluosilicates, fluoaluminates and borates, alkaloid reagents nitrophenols and nitrocresols, fatty and mineral acids, formaldehyde, and ethylene oxide and heavy metals like mercury and copper.

Respiratory Poison

A respiratory poison is associated with blocking of cellular respiration and inactivation of respiratory enzymes as is the case with fumigants like HCN, H_2S and CO (carbon monoxide).

Nerve Poison

The action is primarily associated with the solubility of the toxicant in tissue lipoids and inhibition of acetylcholinesterase in insects and warm-blooded animals.

A chemical substance acctylcholine is formed in the nervous system of insects and mammals mediating in the conduction of the nervous impulses over the microscopic gap between nerves or between nerve and gland or muscle. Acetylcholine, after it has served its function, is destroyed by an enzyme, acetylcholinesterase present in the tissues so that the end-organ (nerve, gland or muscle) may return to its resting state preparatory to repeating its function. If acetylcholine is not destroyed by acetylcholinesterase, it will continue to cause impulses to move along the nerve and cause increased excitation, which induces the production of a new coactive substance by the central nervous system. When produced in large quantities, this natural substance becomes a toxicant and disrupts the normal nerve functions resulting in tremors, convulsions, muscle paralysis and finally death.

Acetylcholine is hydrolysed by the enzyme acetylcholinesterase to form a choline and an acetate-enzyme, the latter reacts instantaneously with water and splits into acetic acid and free enzyme. When required the enzyme is again used to hydrolyse more acetylcholine whereas the acetic acid and choline are used in other physiological processes.

Organic insecticides are active inhibitors of acetylcholinesterase enzyme in insects and mammals. The nerve poisons include the organochlorine compounds (DDT, lindane, paradichlorobenzene, carbon tetrachloride, ethylene dichloride), aromatic and olefinic hydrocarbons (kerosene, gasolene, naphthalene), botanic insecticides (pyrethrine, nicotine), organic phosphates (parathion), *N*-methyl carbamates and miscellaneous chemicals like aniline and carbon disulphide. DDT does not inhibit cholinesterase but initiates high nervous excitation. In the case of poisoning with organophosphatic compounds the phosphorylated enzyme is irreversibly inhibited. On the other hand carbamates are irreversible chlorinesterase inhibitors.

Poisons of a More General Nature or Action

Aldrin, chlordane, dieldrin and toxaphene do not induce neurotoxic symptoms until a latent period has passed. An immediate depressant action is noticeable in organic thiocyanates like Thanite. Some muscular depressants are–phenothiazine, rotenone and ryania.

3. INSECTICIDE MODE OF ACTION GROUPS

A number of new groups of insecticides with different modes of action are being developed and introduced for crop protection; the insecticide mode of action groups presented by AVCARE is furnished here.

Group	Primary Target Site	Chemical Subgroups
1A	Acetylcholine esterase inhibitors	carbamates*
1B		organophosphates*
2A	GABA-gated chloride channel antagonists	cyclodienes
2B		polychlorocycloalthanes
2C		fiproles
3A	Sodium channel modulators	pyrethroids and pyrethrins
4A	Acetylcholine receptor agonist/antagonists	chlornicotinyls
4B		nicotine
4C		cartap, bensultap
5A	Acetylcholine receptor modulators	spinosyns
6A	Chloride channel activators	avermectin, emamectin benzoate
6B		milbemycin
7A	Juvenile hormone mimics	methoprene, hydroprene
7B		fenoxycarb
7C		pyriproxifen
8A	Unknown or non specific action (Fumigants)	methyl bromide

8B		phosphine generating compounds
9A	(selective feeding blockers)	pymetrozine
9B		cryolite
10A	(mite growth inhibitors)	clofentezine, hexythiazox
11A	Microbial disrupters of insect midgut membranes (includes transgenic B.t. crops)	*B.t. tenebrionis*
11B		*B.t. israelensis*
11C		*B.t. kurstaki, B.t. aizawi**
11D		*B.t. sphaericus*
11E		*B.t. tolworthi*
12A	Inhibitors of oxidative phosphorylation, disrupters of ATP formation	organotin miticides
12B		diafenthiuron
13A	Uncoupler of oxidative phosphorylation via disruption of H proton gradient	chlorfenapyr
15A	Chitin biosynthesis inhibitors	acyl ureas
16A	Ecdysone agonists	tebufenozide and related
17A	Homopteran chitin biosynthesis inhibitors	buprofezin
18A	Unknown dipteran specific mode of action	cyromazine
19A	Octopaminergic agonist	amitraz
20A	Site II electron transport inhibitors	hydramethylnon
21A	Site I electron transport inhibitors	rotenone, METI acaricides
22A	Voltage dependent sodium channel blocker	indoxacarb

**all members may not be cross resistant*

[*Source: AVCARE (National Association for Crop Production and Animal Health), October, 1999*]

4. CLASSIFICATION BASED ON CHEMICAL NATURE OF INSECTICIDES

With the advent of more and more newer groups of insecticides, many of them entering the insect body in more than one way, it becomes difficult to classify them based on the mode of entry. This overlapping is avoided if insecticides are classified based on their chemical nature. Two major divisions, viz. inorganic and organic insecticides are recognised. The following is a broad classification of pesticides (includes acaricides, rodenticides and some nematicides also) based on chemical nature.

INSECTICIDES

- Inorganic compounds
  - Arsenicals
  - Flourine compounds
  - Sulphur and lime sulphur
  - Metal Phosphides
  - Other Miscellaneous Compounds
- Organic compounds
  - Hydrocarbon oils
Tar oils
Fixed oils and soaps
  - Animal origin
Nereistoxin
  - Plant origin
  - Synthetic origin compounds

4.1 Inorganic Insecticides

Inorganic insecticides are compounds of antimony, arsenic, barium, boron, copper, fluorine, mercury, selenium, thallium and zinc, which are of mineral origin and elemental phosphorus and sulphur.

Arsenicals Arsenicals are stomach poisons formed of toxic compounds of the apparently non-toxic element arsenic. In an arsenical insecticide the percentage of total arsenic present and the proportion of the water-soluble arsenic have significance. An ideal arsenical insecticide should have very high water-insoluble arsenic content, which should otherwise be readily soluble in the digestive juices of the insect. If the arsenic content is water-soluble, it can enter the foliage and cause "burning" injury to plants. The arsenates are more stable and safer to use on plants than arsenites and hence the latter were used in poison baits and not on plants, as they are phytotoxic. In insects arsenic poisoning causes distintegration of midgut epithelial cells with vacuolised cytoplasm and clumped chromatin of the nuclei. The symptoms of poisoning are regurgitation, torpor and quiescence. Destruction of the insect is primarily due to inhibition of respiratory enzymes.

Arsenicals such as lead arsenate, calcium arsenate, arsenious oxide, sodium arsenite, paris green or copper acetoarsenite, etc. were in use prior to the 1960s. With the synthetic chemicals finding use in crop protection usage of these compounds has been discontinued.

Flourine Compounds Flourine compounds were in use as insecticides since about 1890. They kill insects more rapidly than arsenicals and are less toxic to higher animals and in certain cases safer to use on plants. They are principally stomach poisons and are contact poisons to a limited extent. They are irritating to the appendages of insects. As with arsenicals, the fluorine content and solubility in the digestive juices of the insect are attributed to the insecticidal properties of fluorine compounds. The symptoms of fluoride poisoning are spasms, regurgitation, flaccid paralysis and death. In poisoned insects fluoride combines with magnesium to form magnesium fluorophosphate and thus inhibits phosphate transfer in oxidative metabolism.

Sodium fluoride, sodium fluosilicate, and cryolite or sodium fluoaluminate were in use in the past.

Sulphur and Lime Sulphur

Sulphur: It is primarily a contact poison and in a finely ground dust form (95 % of them passing through a 325 mesh sieve) it is used for insecticidal purposes. The flow of dust is made more free by the addition of about 3 % of the conditioner tricalcium phosphate. Wettable sulphur is prepared by adding a small percentage of wetting agent and also about 0.2 per cent of a synthetic surface active agent. Though sulphur is primarily used as an acaricide it is also used as a diluent for some insecticidal dusts. Sulphur which is commonly used is not toxic other than being irritating to eyes.

Lime sulphur: In 1852 Grison first used it as a fungicide and Dussey in 1886 found it useful in the control of San Jose scale. It is prepared by boiling lime and sulphur together in water. Among the several chemical compounds formed, the polysulphides (calcium pentasulphide and calcium tetrasulphide) are the active materials, which possess insecticidal activity. This has been used for the control of aphids, scales and mites on fruit trees. When liquid lime sulphur is mixed with a stabiliser and evaporated it results in dry lime-sulphur, which in general is less effective than the liquid form.

Metal Phosphides

Aluminium phosphide: It is an insecticidal fumigant. It releases hydrogen phosphide (phosphine, PH_3) in the presence of moisture. It is used for fumigating animal feed, bulk grain, tobacco stakes, etc. to protect them from storage pests and also for space fumigation of warehouses and flour mills. For out-door use it was used for killing rats in burrows. Available in tablets, plates or strips. Its use is permitted under strict supervision by trained and approved personnel/agencies.

Magnesium phosphide: It reacts with atmospheric moisture and releases hydrogen phosphide which is an effective insect-killing gas. It finds use as in the case of Aluminium phosphide. It is available in the form of tablet, strips and plates. The conditions of its usage is the same as in the case of Aluminium phosphide.

Zinc phosphide: It is primarily a rodenticide and is a heavy, dark-grey powder with disagreeable garlicky odour; it was previously used in the control of cockroaches in Europe and mole crickets in Italy. Baits containing 2 % zinc phosphide are recommended for control of rats. In rats the chemical reacts with the hydrochloric acid present in the stomach and releases phosphine gas, which is lethal to the rat.

Other Miscellaneous Compounds: Other compounds which have been found to be stomach poisons of limited use are:

Phosphorus : A paste is prepared by grinding yellow phosphorus in the presence of water and then mixing it with flour a paste is prepared. Sometimes glycerin is added to it. This is used as a bait for cockroaches.

Thallium sulphate: It is a crystalline water-soluble material, which is mixed with a sweet or fatty carrier and used as bait for ants.

Borax or Sodium tetraborate: This finds use in the control of housefly maggots in manure pits. The maggot-infested wounds of animals can be treated and the flies repelled with an emulsion of borax in oil or glyceroboric acid.

Boric acid : It is a stomach poison for cockroaches.

Formaldehyde: It is used in baits for the control of houseflies. Its 40 % solution in water is called formalin.

Metallic mercury: The ointment prepared by incorporating metallic mercury in a heavy oil-like vaseline was used for the control of lice on poultry or on man.

Mercuric chloride and *Mercurous chloride* were used for controlling root infesting maggots and flea beetle larvae. Use of mercuric chloride in book bindings and ant tapes repel ants, cockroaches and termites.

Potassium antimonyl tartarate: It is known as tartar emetic and is a water-soluble salt. It is an ant poison.

Bordeaux mixture: It is a blue coloured suspension prepared by reacting equivalent amounts of copper sulphate with calcium hydroxide. When sprayed it leaves a bluish-white deposit and sometimes repels flea beetles and leafhoppers. However, it is used primarily as a fungicide.

Sodium selenate: It is a water soluble salt. It acts as a systemic poison when applied to soil and brings about control of mites and aphids on ornamental plants in green houses. As it is a cumulative poison, it should never be applied to soil in which food crops will be raised.

4.2 Organic Insecticides

4.2.1 Hydrocarbon Oils

The mineral oils are the petroleum oils derived from sedimentary rocks. Complex solution of hundreds of hydrocarbons are present in the petroleum oils. Kerosene, gasoline lubricating oils, asphalt, tar and many other mixtures are derived from them. In their natural state, oils are highly phytotoxic, but under certain conditions, if applied with an emulsion they may prove to be safe for use on plants. Oils have become increasingly important since 1874 with the discovery of a good formula for a kerosene, soap and water emulsion. They are also used as solvents or carriers for insecticides. In the mineral oil the insecticidal activity is due to certain fractions of the heterogenous mixture of saturated and unsaturated chain and cyclic hydrocarbons in it. The quality of oil is determined by its viscocity, boiling or distillation range, and sulfonation rating, i.e. purity or degree of refinement.

Viscosity is expressed in terms of the time in seconds for 60 ml of oil to flow through a standard orifice at a definite temperature of 100° F. Oils possessing a higher value are not safe for use on plants. It must be borne in mind that the oil from different countries having the same viscocity rating when sprayed on leaves, may react quite differently. Similarly, with the increase in distillation range or boiling phytotoxicity also increases. The lighter oils are more volatile and escape into the air soon whereas the heavier oils exhibit contact with the surface for a longer time due to their less volatile nature and thus prove to be more efficacious against insects.

The non-stable unsaturated compounds in the oil form compounds that are toxic to plants and their amount in the oil is tested by sulfonation test. The unsaturated hydrocarbons in the oil react with strong sulphuric acid when treated and leave the unreacted part, i.e. the sulfonated residue (UR). The UR value is expressed in terms of percentage to interpret the purity of the oil. Highly refined summer oils have a UR rating of 90 to 96 % whereas rating is 50 to 90 % for dormant oils. Following is the classification of insecticidal oils based on the time of usage.

Summer Oils

They are highly refined oils and are less phytotoxic when applied on foliage. The spray concentrations vary from 0.25 to 2.0 % oil. They are used in water emulsion sprays for the control of insect pests like coccids, aleyrodids, and other pests infesting trees, shrubs and ornamentals.

Dormant Oils

They are heavy and less refined oils and are applied on fruit trees and shrubs having no foliage on them during the dormant season. The dormant oil is available in emulsifiable form having 85 to 99 % of actual oil. The spray concentrations vary from two to five per cent of oil. It is sprayed for the control of coccids, aphids, certain mites, etc.

Superior or Supreme Spray Oils

They are again dormant spray oils of high paraffinic and low aromatic content possessing insecticidal action to a satisfactory extent and increased plant safety. They are applied on apple trees from the bud stage up to the time leaves are about 4 cm long for the control of aphids, scales and mites.

Spray Oils

They are diluted with water and applied as an emulsion containing one to four or more per cent oil. When sprayed a continuous film of oil envelops the insects and mites and their eggs, which interferes with their respiration and causes death, by asphyxiation. Spray oils are manufactured from paraffinic-base crudes and naphthenic-base crudes and the preparations of the latter are less effective than the former.

The three types of spray oils in general use are:

(i) *Oil emulsions or concentrated emulsions:* They form stock preparations of fluids or pastes consisting of 80 to 90 % oil emulsified into a small amount of water. The preparation readily mixes with water when added to it in the spray tank.

(ii) *Emulsive or Emulsible oils*: The preparation contains 95 to 99 % oil and an emulsifier. A preliminary agitation is required with a small quantity of water in the spray tank. Certain other formulations of these oils, referred to as *miscible oils*, produce an emulsion instantly when poured into water in a spray tank and the emulsion is stable.

(iii) *Tank-mix oils*: These are prepared just before use and form "quick-breaking" emulsions. In a preparation the oil and spreader are added to the water in the spray tank and emulsified by agitating and pumping.

Oils as solvents and carriers: Diesel fuel is often used as a carrier for toxicant applied by aircraft. In household sprays kerosene (especially deodorised type) is used as a solvent. Oils are relatively cheap and easy to mix with good spreading capacity and low toxicity to animals, and insects have not developed any resistance to them. However, they exhibit relatively low toxicity to most insects and instability in storage. They are phytotoxic and also cause injury to sprayer parts such as rubber hoses.

The lubricating oil-emulsions, the white and summer-oil emulsions, coal tar-oil emulsions, distillate-oil emulsions, kerosene emulsions, carbon bisulphide emulsion and the miscible oils have various trade names.

4.2.2 Tar Oils

Among coal-tar oils creosote oil and green oil or anthracene are useful for insecticidal purposes. Anthracene oils is used for wood preservation.

4.2.3 Fixed Oils and Soaps

Fixed oils are derived from both plants and animals and include oils like castor oil, linseed oil, soybean oil, fish oil etc. They are glycerides and with alkaline bases they saponify or form soaps, setting free glycerin. Fish oil is used in making insecticidal soaps. Soybean oil is also used in insecticides.

Soaps dissolved in water at sufficient quantities act as contact insecticides and have been used for pest control since 1787. A soap is a salt of a fatty acid and an alkali-metal base such as potassium or sodium hydroxide; the former base forms soft soap and the latter, hard soap. The fatty acids are derived from animal and vegetable oils and may include oleic, palmitic or steric acids. Rosin fish-oil soap is available as a commercial insecticide soap and is effective against hairy caterpillars and scale insects. In the preparation of emulsions and as spreaders, wetting agents and stabilisers for pyrethrum and nicotine sprays, soap is used. Soft soaps are used in solution in oils to form the miscible oils.

4.2.4 Animal Origin

Nereistoxin: It is a toxin, chemically known as 4-(N,N-dimethylamino)-l,2-ditholano, isolated from the marine annelids *Lumbrineris* (*Lumbriconereis*) *heteropoda* and *L. brevicirra*. It was found to possess insecticidal activity and in insects caused paralysis due to competitive synaptic blocking action in the central nervous system. Among various related compounds synthesised and tested, the compounds belonging to the group of 1,3-dithiol esters showed insecticidal activity. A product known as cartap, having the chemical name 1,3-bis (carbamoylthio)-2-(N,N-dimethylamino) propane hydrochloride, has been proved to be a practical insecticide against rice stem borer and cabbage diamondback moth.

4.2.5 Botanical Insecticides

Toxicants derived from plants have been and are still used as arrow-tip poisons and fish poisons. Plant products are used in many ways in insect control and among these azadirachtin, nicotine, pyrethrum and rotenone are well known. They are dealt with in a separate chapter.

Volatile Oils from Plants: The volatile or ethereal oils are obtained from special glands of plants and their pungent odour is characteristic of the plant source. The oils are not saponified and are not greasy or viscous. The volatile oils are chiefly used as attractants in baits or as repellents. The attractants include eugenol and geraniol. Citronella and oil of cedar are repellents. Other common examples of volatile oils from plant sources are menthol, camphor, oil of peppermint and wintergreen.

4.3 Synthetic Organic Insecticides

Synthetic organic compounds dominate the field of insecticidal control today. As early as 1892 dinitrocresol was in use as insecticide in Germany and by 1932 several thiocyanates became available commercially. After the Second World War DDT came into prominence as a potent insecticide which revolutionised plant protection. During the World War II certain german scientists developed highly toxic organophosphates and from these insecticides like parathion, TEPP, Schradan, demeton, etc. were obtained. Subsequently in the 1950s carbamates got introduced. In the last four decades vigorous developments have taken place in synthetic chemicals and many new classes of compounds including insect growth regulators, pyrethroids, azadirachtin, etc. have been introduced. Due to intensive research many more new products are being discovered.

The following are some of the important synthetic organics used in plant protection.

4.3.1 Dinitrophenols

The dinitrophenols are derivatives of 4,6-dinitro 2-alkylphenols and their salts or esters.

DINOCAP: It is chemically 2-(l-methyl-n-heptyl)-4,6-dinitrophenyl crotonate or 4,6-dinitro-2-caprylphenyl crotonate. It was first introduced by Rohm & Haas Company in 1946. It is an acaricide and fungicide registered as 48 % EC. Its acute oral LD50 for rat is 980 to 1190 mg/kg.

4.3.2 Organic Thiocyanates:

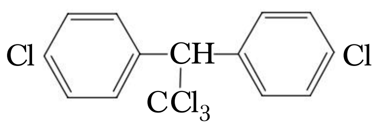
Several insecticides of organic thiocyanates were in use since 1932. They are contact poisons and act on the nervous system of insects. These compounds possess SCN or isothiocyano CNS group and exhibit quick knock down effect.

4.3.3 Organochlorine Compounds

Organochlorine compounds have carbon, hydrogen and chlorine as their basic molecular constituents and some compounds may have oxygen and sulphur also.

DDT

Dichlorodiphenyl trichloroethane ($C_{14}H_9Cl_5$) was first synthesised in 1874 by a German chemist, Othnar Zeidler, but its insecticidal value was not discovered until about 1939 by Paul Muller*. Though DDT is a mixture of substituents, the two isomers *pp'*-DDT and *op'*-DDT are the chief substituents. The principal ingredient of technical DDT, *pp'*-DDT, is 1,1,1–trichloro 2,2,di-(4-chlorophenyl) ethane or 1,1,1-trichloro-2,2-bis(*p*-chlorophenyl) ethane. The structural formula of DDT is:



The product obtained by reacting chloral (or its alcoholate or hydrate) with monochloro-benzene in the presence of concentrated sulphuric acid is technical DDT, which is a white to cream coloured amorphous powder and is composed of up to 14 chemical compounds. The technical product is formed of 65 to 80 % of active *pp'*-DDT, 15 to 21 % of the nearly inactive *op'*-DDT or 1, 1, 1-trichloro-2-(*o*-chlorophenyl) -2-(*p*-chlorophenyl) ethane, up to 4 % of DDD or TDE, up to 0.15 % of l-(*p*-chlorophenyl) 2,2,2- trichloroethanol and

* P. Langer *et al.*, 1944, *Helv. Chim. Acta* **27**: 892.

traces of *O-O'* DDT or 1, 1, 1 -trichloro-2,2-bis-(*o*-chlorophenyl) ethane and bis-*p*-(chlorophenyl) sulfone. The requirements of technical DDT are a setting point of 89° C or above, and presence of 9.5 to 11 % hydrolysable chlorine and less than 1 % volatile and alcohol-insoluble material. Technical DDT is insoluble in water, fairly soluble in most organic solvents and highly soluble in aromatic hydrocarbons such as xylene. In alkaline solution it is dehydrochlorinated to form 1.1-dichloro-2, -bis-(*p*-chlorophenyl)ethylene, which has no insecticidal property. However, it is stable under most conditions. It has a very low vapour pressure.

DDT is a contact and stomach insecticide having a longer residual action. It affects the sensory organs and nervous system and causes violent agitation, which is followed by paralysis and death. However, it acts slowly. To mammals it is relatively non-toxic but in oil solution is absorbed by the skin. When animals are fed with foliage treated with DDT, accumulation of the chemical in animal fat and its secretion in the butterfat of lactating animals has been noticed. It is relatively safe for use on large number of crops but exhibits phytotoxicity on sensitive crops like cucurbits. When applied at low concentrations DDT has been found to stimulate plant growth in crops like potato, tomato, brinjal, cabbage, etc. much like plant hormones do. DDT is effective against a wide range of insect pests and several of them have developed resistance to it. As DDT application kills natural enemies of certain groups of insects such as aphids, scales and mealy bugs and also mites, they develop to pest proportions.

In various organisms DDT is metabolised in the following five routes: Oxidised to (i) dicofol in insects, or (ii) dichlorobenzophenone, or (iii) DDA (dichlorodiphenylacetic acid) in vertebrates; (iv) dehydrochlorinated to DDE in animals; and reductive dechlorinated to form DDD or TDE (tetrachloro-diphenylethane) in mammals. In man DDA is the principal metabolite found in the urine. In animals when DDT gets accumulated and stored in fatty tissues it is slowly converted to DDE and finally excreted as DDA. Strains of insect species resistant to DDT possess higher amounts of the enzyme DDT'ase, which converts DDT to inactive DDE. Several DDT analogues also possess insecticidal activities.

Its use in agricultural sector has been withdrawn in India and permitted to be used only for mosquito control under public health programme as 50% WP or 75% WP.

Chlorobenzilate

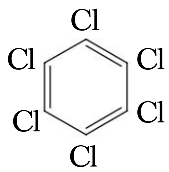
Chlorobenzilate is an acaricide effective against all stages of mites. Gasser in 1952 described its acaricidal properties. It is a yellowish viscous oil. The technical material contains 90 % of the active compound ethyl-*p,p'*-dichlorobenzilate. It is insoluble in water but soluble in benzene, deodorized kerosene and methyl alcohol and gets hydrolysed in alkali and in strong acids to the inactive *p,p'*-dichlorobenzilic acid and ethanol. Its oral and dermal LD_{50} values for rat are 700 to 3200 and 5000 mg/kg, respectively. Its use in the form of strip only has been registered in India.

Dicofol ($C_{14}N_9Cl_5O$)

l,l-bis-(*p*-chlorophenyl), 2,2,2-trichloroethanol or 2,2,2-trichloro-l, l-di-(4-chlorophenyl) ethanol (Dicofol) was reported as an acaricide by Barker, J. S. and F. B. Maugham in 1956[1] and commercially introduced as Kelthane. It is insoluble in water but soluble in organic solvents. It forms the inactive *p,p'*-dicholorobenzophenone and chloroform in the presence of alkali. It is a specific acaricide effective against all stages of mites and is harmless to bees and predators. It has long residual effect. It is used for the control of mites on tea. Its oral and dermal LD_{50} values are 587 to 595 mg/kg for rat and >2000 mg/kg for rabbit, respectively.

HCH

1,2,3,4,5,6-Hexachlorocyclohexane ($C_6H_6Cl_6$) (HCH) was referred earlier as BHC (benzene hexachloride), which is incorrect as HCH could be confused with hexachlorobenzene. Its structural formula is:



This compound was first synthesised in 1825 by Michael Faraday. Its insecticidal properties were described by A. Dupire and by M. Recourt[2] and by R.E. Slade[3]. However, the fact that the insecticidal principle of the technical HCH is the gamma-isomer was made known by F.J.D. Thomas in 1943 in England. HCH is produced by the chlorination of benzene. Among the 13 possible isomers found in varying proportions in HCH, the gamma isomer is insecticidally most active. The gamma isomer comprises about 12.5 % of crude HCH. The crude HCH is greyish or brownish amorphous solid and has a strong musty odour. The crude product consists of 10 to 18 % of the active gamma isomer, four other nearly inactive stereoisomers, viz. 55 to 70 % α-isomer, 5 to 14 % β-isomer, 6-8 % γ-isomer and 3-4 % β isomer, up to 4 % heptachlorocyclohexane and a trace of

1. *J. Econ. Entomol.*, 1956, **49:** 458.
2. *C.R.Hebd. Seances Acad. Agric. Fr.*, 1942, **20:** 470.
3. *Chem. Ind.* (*London*), 1945 p. 134.

octachlorocyclohexane. It is a stable compound but is broken down by alkali principally to 1,2,4-trichlorobenzene and three moles of hydrogen chloride. It acts as a stomach and contact poison and also to some extent as a fumigant. It is more toxic to insects than DDT and finds use in control of mosquitoes. It is also safe to use on a variety of crops but phytotoxic on some especially curcurbits. The oral and dermal LD_{50} values of gamma HCH (lindane) for rat are 200mg/kg and 500 to 1000 mg/kg, respectively. HCH poisoning increases respiration rate and symptoms of poisoning are tremors, ataxia, convulsions and prostration.

It is generally formulated as a 50 % wettable powder or as 5–10 % dust and is used for the control of a wide variety of pests of crops. In some treated plants, especially vegetable crops, HCH taints or produces off-flavour. When applied to soil for control of soil pests of tuber crops or on foliage of edible crops it sometimes causes severe tainting as in potato, lettuce, etc. and makes them unpalatable. When applied as a dust or spray it is very irritating to mucous membranes and eyes. Use of HCH in India has been withdrawn.

Lindane

The product containing gamma isomer of HCH of not less than 99 % purity is commonly referred to as lindane and the name was proposed in 1949 after Van der Linden, a German chemist who isolated this isomer in 1912. It is white to colourless, crystalline, odourless, unstable in the presence of alkali and does not accumulate in the fat of animals to any marked extent. It is a contact and stomach poison and has some fumigant properties. Lindane is safer than HCH on plants but more toxic to insects. It is formulated as 20 % emulsifiable concentrate, which is useful for the control of a large number of insect pests, especially the sugarcane shoot borer. Lindane 0.65 % dust is used for the control of pests of vegetable crops and stored products. Lindane 10 % granule has been reported to be effective in controlling the rice yellow borer.

4.3.4 Cyclodiene Insecticides

These are highly chlorinated cyclic hydrocarbons with “endomethylene-bridged” structures, prepared by the Diels-Alder diene reaction. The toxicity of the compounds is attributed to their high lipoid solubility. Though they are known to act on the ganglia the precise bio-chemical lesion responsible for toxic action is not understood. Symptoms of poisoning are hyperactivity, convulsions and prostration.

Chlordane

Chlordane ($C_{10}H_6Cl_8$) or Octachlor is 1,2,4,5,6,7,10,10 - Octachloro - 4,7,8,9-tetrahydro-4,7 methyleneindane. In 1945 C.W. Kearns* and his associates described its insecticidal properties. The technical material is a brown viscous liquid and has a odour resembling cedar. It has a light fumigant action but also possesses some residual activity. It is a stomach and contact poison. It is toxic to bees. Its oral and dermal LD_{50} values for rat are 283 and 1600 mg/kg respectively. Its use in India has been withdrawn.

Heptachlor

Heptachlor is 1,4,5,6,7,10,10 heptachloro-4,7,8,9-tetrahydro-4,7-methyleneindane. The technical product containing about 67 % heptachlor is a soft waxy solid. It is a nerve poison. Its oral and dermal LD_{50} values for rat are 40 and 200-250 mg/kg respectively. Heptachlor residues are slowly converted to heptachlor epoxide in and on plants and in animal tissues and this has the same mammalian toxicity and insecticidal activity. It was recommended for the control of grasshopper, soil insects like white grubs, wire-worms, termites, etc. Its use in India has been withdrawn.

Aldrin

Aldrin is 1,2,3,4,10 10-hexachloro-l,4,4a,5,8,8a- hexahydro-*exo*-l, 4-*endo*-5,8-dimethanonaphthalene. The name Aldrin was given to the chemical to honour the German chemists Kurt Alder and Otto Diels who received the Nobel Prize in Chemistry in 1950 for their work on diene synthesis used in formulation of cyclodiene insecticides. In the living tissues of plants, mammals and insects aldrin gets rapidly converted to dieldrin. Its oral and dermal LD_{50} values for rat are 40 to 50 and 200 mg/kg respectively.

It has considerable residual effectiveness and was used as a soil insecticide for the control of termites, white grubs, etc. It was used in the control of locusts and grasshoppers in India. Its use in India has been withdrawn.

Dieldrin

Dieldrin is 1,2,3,4,10,10-hexa-chloro-6-7-epoxy-l,4,4a,5,6,7,8,8a-octahydro-*exo* l,4-*endo*-5,8-dimethanonaphthalene or the epoxide of aldrin. Dieldrin was named after the German chemist Otta Diels. The acute oral and dermal LD_{50} values for rat being 40 and 100 mg/kg respectively. It was useful in the control of pests infesting crops, in household

* *J. Econ. Entomol.*, 1945, **38:** 661.

sprays for the control of cockroaches, flies and mosquitoes, and in the control of termites, grubs and larvae feeding on roots of plants. The formulation 18% solution is registered in India.

Endrin

It is l,2,3,4,10,10-hexachloro-6-7-epoxy-l,4,4a,5,6,7,8,8a-octohydro-*exo*-l,4-*exo*-5,8-dimethano-naphthalene or the *exo exo* isomer of dieldrin. Its use in India has been withdrawn.

Endosulfan

Endosulfan, is 6,7,8,9,10,10-hexachloro- l,5,5a,6,9,9a- hexahydro -6,9 methano-2,4,3-benzo(e)-dioxathiepin-3-oxide. It is both a chlorinated hydrocarbon and an organic sulphite. Its empirical formula is $C_9H_6Cl_6O_2S$. In 1956 W. Finkenbrink* described its insecticidal properties. The technical material is a brown crystalline solid, insoluble in water but soluble in xylene. It consists of two stereoisomers, viz. α and β stereoisomers, and inactive 1,4,5,6,7,7 hexachloro-2, 3-bis- (hydroxy-methyl)-bicyclo-(2.2. l)-heptene-5. It has a slight fumigant action besides being a stomach and contact poison. It has been found useful in the control of aphids, caterpillars, plant bugs and borers. Its use does not encourage secondary infestation of mites. It is not harmful to bees and natural enemies of pests. It is formulated as 35 % emulsion concentrate. Its acute oral and dermal LD_{50} values for rat are 110 and 74 to 130 mg/kg respectively.

4.3.5 Organophosphorus Insecticides

These insecticides are characterised by the molecule having one or more rarely two atoms of phosphorus, and are usually derivatives of phosphates (PO_4). In Germany during World War II Schrader discovered the insecticidal potency of this chemical group and since then a large number of compounds have been synthesised. They mainly act as contact and stomach poisons; and some are systemic, some slowly give out vapours which have fumigant action. The phosphorus esters owe their biological activity to inhibition of enzyme cholinesterase and this is determined by the magnitude of the electrophilic character of the P atom, the strength of the P-X bond and the steric nature of the substituents. It has been shown that the phosphate esters (P-O) are more active as the P is much more electrophilic than in the phosphorothionate esters (P-S), the latter, being stable, is activated by oxidation to the corresponding P-O compound in the animal body. The P-X bond of the toxicant is broken during inhibition process due to its bimolecular reaction with enzyme cholinesterase. In the highly toxic compounds strong electron withdrawing

* *Nachrichtenbl.Dtsch.Pflanzenschutzdienstes* (*Brawnschweig*) 1956, 8 : 183.

substituents, such as p-NO_2 and CH_3S, may be found. Similarly the alkyl and alkoxy substituents of phosphates and phosphonates also influence the electrophilic nature of P atom. Decrease in toxicity and increase in stability has been noticed with increasing chain length and with chain branching of the compounds. Further, incorporation of –Cl or –CH_3 in the meta position of the aryl ring of parathion-type compounds reduces the mammalian toxicity appreciably without affecting its insecticidal activity.

In higher animals and insects cholinesterase is an essential constituent of the nervous system. Therefore, the capacity of the central P atom of the organophosphorus toxicant to phosphorylate the esteratic site of the enzyme cholinesterase contributes to the biological activity of the compound. The phosphorylated enzyme is irreversibly inhibited. This disrupts the normal function of rapid removal and destruction of acetylcholine from the nerve synapse. As a result acetylcholine responsible for transmission of nerve impulses across the synapse accumulates and causes derangement of the nervous mechanism and death.

Symptoms of poisoning due to organophosphorus compounds are hyperactivity, tremors, convulsions, paralysis and death in insects and muscarinic effects such as nausea, salivation, lachrymation and myosis, nicotinic effects such as muscular fasciculations and central effects such as giddiness, tremulousness, coma and convulsions in higher animals.

The organophosphorus pesticides are classified, based on the way in which the phosphorus atom is found in the combination, into phosphates, phosphonates, phosphor othionates, phosphorothiolates, phosphorothiolothionates (phosphorodithioates), phos phonothiolothionates (phosphonodithioates), phosphonothionate, phosphoramidate, phasphoramidothioate, etc.

The following are some important compounds among different groups of organo-phosphorus chemicals used in crop protection.

Acephate

Acephate, $C_4H_{10}NO_3PS$, is *O, S*-dimethyl acetyl-phospharamidothioate. It is a white solid; melting point 82-89°C; specific gravity. 1.35; volatility low, relatively stable; solubility is approximately 65 % in water but relatively low being less than 5 to 10 % in organic solvents. It is an insecticide of moderate persistence with residual systemic activity. It is effective against caterpillars, lace bugs, leaf miners, leaf rollers, leafhoppers, mealy bugs, thrips, etc. It is formulated as 75 % soluble powder. Its acute oral LD_{50} to rat is 866-945 mg/kg, dermal for rabbit >2000 mg/kg.

Cadusafos

It is a nematicide and soil insectcide. Chemically it is O-ethyl S,S-di-sec-butyl phosphorodithioate or O-ethyl S,S-bis(1-methylpropyl) phosphorodithioate. Cadusafos 10%G has been found effective against banana nematode when applied at 20-30 g/plant. The acute oral LD_{50} for rat is 679 mg/kg (male), 391 mg/kg (female); dermal rabbit 155 mg/kg (male), 143 mg/kg (female) in respect of 10% G.

Chlorfenvinphos

Chlorfenvinphos, $C_{12}H_{14}O_4C_{13}P$, is combined isomers of 2-chloro-1-(2,4-dichlorophenyl) vinyl diethyl phosphate. Technical material contains not less than 92 % (weight) active *trans* and *cis* isomers of the toxicant. It is an amber liquid with a mild chemical odour and is not inflammable. It is slightly soluble in water and miscible with acetone, xylene, alcohol, kerosene, corn oil and propylene glycol. It decomposes very slowly in the presence of water. Its acute oral and dermal LD_{50} values for rat are 10 to 155 and 108 mg/kg respectively. It is a contact insecticide and in some cases may be translocated in plants. It is active against pests belonging to orders Diptera, Lepidoptera and Coleoptera. It is particularly useful for the control of rootfly larvae, Colorado potato beetles, cereal leaf beetles and corn rootworms. It is effective against pests resistant to chlorinated hydrocarbons. It does not leave any harmful residues in crops and soil at normal recommended dosages. Formulation registered in India is 10% Gr.

Chlorpyriphos or Chlorpyrifos

Chlorpyriphos is O, O-diethyl O-(3,5.6-trichloro-l-pyridyl) phosphorothioate. Its empirical formula is $C_9H_{11}Cl_{13}NO_3PS$. It is a white crystalline substance with mild mercaptan odour; m.pt. 41.5 - 43.5°C. It has extremely low solubility in water but readily soluble in most organic solvents. It is relatively stable to hydrolysis and oxidation. It is slowly hydrolysed to 3,5,6- trichloro-2-pyridinol. It may not probably be compatible with highly alkaline materials especially Bordeaux mixture and liquid lime-sulphur. It is a contact and stomach poison with vapour action also. Its acute oral LD_{50} for female rat is 135 mg/kg, male rat 163 mg/kg: dermal for rabbit 1000 to 2000 mg/kg. It is effective against many pests of rice and other crops, mosquitoes and household pests, soil inhabiting insects particularly termites and certain mites. It is applied at a dosage rate ranging from 0.05 to 0.5 kg a.i./ha depending on the pest species. Formulations registered are 20%EC and 10% Gr and 50% EC for termite control.

Coumaphos

Coumaphos, is 3-chloro-4-methyl-7-coumarinyl diethyl-phosphorothionate or O,O-diethyl-O- (3-chloro-4-methyl-2-oxo-2H-l-benzopyran-7-yl) phosphorothionate. It is a tan crystalline solid, insoluble in water and soluble in organic solvents. It is a systemic insecticide used in the control of animal pests. Its acute oral and dermal LD_{50} for rat are 13 to 180 and 860 mg/kg respectively. Its trade names have been Asuntol, Co-Ral, Muscatox, etc.

Diazinon

Diazinon, $C_{12}H_{21}N_2O_3PS$, is a phosphoric acid ester. It is diethyl 2-isopropyl-6-methyl-4-pyri- midinyl phosphorothionate (or) Thiophosphoric acid-(2-isopropyl-4-ethyl-pyrimidyl-(6)-diethylester. It is a colourless liquid with a slight characteristic odour. It is soluble to 0.004 % in water and mixes with ether, alcohol, benzol and similar hydrocarbons and with deodorised kerosene, cyclohexane and petroleum ether. It is hydrolysed in alkalis and acids. The technical product is 90% pure, clear yellowish-ochreish slightly viscous liquid with a characteristic odour. It is a contact and stomach poison and has a fumigant effect and penetrative quality. Its acute oral and dermal LD_{50} for rat are 150 to 220 and 500 to 2,000 mg/kg respectively. Diazinon is chiefly useful in the control of resistant houseflies, bedbugs, ectoparasites on animals, insect pests of crops and certain mites. It has also a nematicidal effect. Diazinon gives excellent control of ectoparasites on domestic animals and it is chiefly used for dipping and spraying cattle and sheep. It controls all the major ectoparasites and protects the sheep from primary blowflies. Diazinon is not eliminated with milk.

In agriculture diazinon is useful in the control of a wide variety of pests of crops. It is effective against lepidopterous larvae, bugs, thrips, beetles, flies and certain mites. It has proved to be an outstanding chemical for the control of most sucking insects, borers and leaf caterpillars and gall midge on rice when applied in granular form at 1.5 to 2 kg active ingredient/ha. Diazinon is also effective against soil pests. It is effective against cabbage rootfly, onion maggot, turnip maggot, seed corn maggot, wheat bulbfly, carrot rustfly, wireworms, lepidopterous larvae, field cricket, lettuce root aphid, and certain myriapods infesting potatoes in France and Belgium.

Formulations are: 40% WP, 20,25 or 60% EC, 2–5% dust and 5 or 10% granule.

Dichlorvos (DDVP)

Dichlorvos ($C_4H_7O_4Cl_2P$) is 2,2-dichlorovinyl dimethyl phosphate or O, O-dimethyl -2, 2-dichlorovinylphosphate. It is a pleasant smelling, colourless liquid. It is soluble in water and most organic solvents. It gets hydrolysed slowly in neutral and acid media and rapidly in alkaline medium. Its acute oral and dermal LD_{50} values for rat are 25 to 30 and 75 to 900 mg/kg. It is moderately toxic to fish and highly toxic to bees. It acts as a contact, and stomach poison and fumigant and has good penetration properties. It brings about rapid knockdown of the insect. As the toxicant volatilises soon after application, it can be used on all crops until shortly before harvest and it also does not impart any taint. It has no ovicidal action. It is used in baits and aerosol formulations for the control of insects of home and public health such as flies and mosquitoes in open places and for the control of insects of stores and food processing plants such as flies and moths in stores, mills, bakeries, dairies, etc. It is also useful for the control of insect pests of mushrooms.

It is effective against locusts when applied from aircraft at 80 to 120 g active ingredient/ha. Dichlorvos is also effective against pests of crops such as lepidopterous larvae, leaf miners, sucking insects and mites. It is available as 76% SC in India. It is useful in the control of cockroaches.

Dimethoate

Dimethoate (C_5HOPSN) is dimethyl S (N-methyl carbamoylmethyl) phosphorothiolothionate or N-monomethyl-amide of O,O-dimethyl-dithiophosphoryl-acetic acid or O, O-dimethyl-S (mercapto-N-methyl-acetamides) dithiophosphate or 0,0-dimethyl-S (N-methyl-carbarnoyl-methyl) phosphorodithioate.

It is a white crystalline solid with slightly mercaptanic odour. Technical material contains 94 to 96 per cent dimethoate, white crystalline solid with unpleasant odour. It is soluble in a number of organic solvents such as chloroform, alcohol, ethyl ether, acetone, benzens, toluene, cyclohexanone, acetophenone, etc. It is rather unstable in alkaline media. Its acute oral and dermal LD_{50} to rat respectively are 200 to 300 and 700 to 1150 mg/kg. It is a systemic and contact poison effective against sucking insect pests and mites of a wide variety of crops and fruitflies. It is phytotoxic on certain varieties of sorghum, some varieties of hops (Golding) and olives (Coratina, Vernina, Marsella), figs, chrysanthemums, begonia and jacobinias. Neither dimethoate nor its biologically active conversion products can be detected three to four weeks after treatment. Dimethoate 30 % EC registered in India.

Disulfoton or Thiodemeton

Disulfoton ($C_8H_{19}O_2PS_3$) is diethyl S-2-(ethylthio) ethyl phosphorothilothionate or O,O-diethyl-S-2-(ethylthio) ethyl phosphorodithioate. It is a colourless oily liquid with characteristic odour, soluble in most organic solvents such as acetone, alcohol, ether, etc. It is a systemic insecticide and acaricide possessing residual action for 6 to 12 weeks. Its acute oral and dermal LD_{50} to rat are 4 and 50 mg/kg respectively. It is applied as a granule or used in seed dressing. Sufficient moisture should be present in the soil for it to act effectively. It is recommended at dosages varying from 1 to 2 kg active ingredient per hectare for the control of sucking insects and mites infesting rice, cereals, potato, cotton, groundnut, coffee, beans, peas, cabbage, tomatoes and ornamental plants. It is also effective against sorghum shootfly. Formulation: 5 % granule.

Ethion

Ethion ($C_9H_{22}O_4P_2S_4$), is tetraethyl SS'-methylene bis- (phosphorothiolothionate) or 0, 0, 0', 0'-tetraethyl -S,S'-methylene bis phosphorodithioate. It is slightly soluble in water and miscible in xylene, methylated naphthalene and kerosene. Its acute oral LD_{50} for rat is 96 mg/kg and dermal LD_{50} for rabbit is 915 mg/kg. It is useful for the control of many aphids, scales, leaf miners, leaf hoppers, pear psylla, sorghum midge, codling moth, seed corn maggot, onion maggot, Lygus bugs, thrips and mites (including eriophyid mites). It is phytotoxic on certain apple varieties. Formulation registered in India is 50% EC.

Fenitrothion

Fenitrothion ($C_9H_{12}P_5NPS$) is dimethyl 3-methyl-4-nitrophenyl phosphorothionate or 0,0-dimethyl-0-(3-methyl-4-nitrophenyl) phosohorothioate. Technical material is 95 % pure, yellowish brown oily liquid with a faint smell. It is insoluble in water, soluble in alcohol, ether and low boiling aromatics. It is unstable in alkaline medium. Its acute oral and dermal LD_{50} for rat are 250 to 673 and 1500 to 3000 mg/kg respectively. It is toxic to bees. It is a contact and stomach poison and has a good depth action. Phytotoxicity may be caused on *Brassica* crops and certain susceptible apple varieties and on cotton at high dosages. It is recommended against a wide range of pests of crops and certain mites, and especially for the control of pests of rice. It is also used for the control of mosquito larvae, bed bugs and poultry lice, fleas, mites, ticks and ectoparasites of livestock and pet animals. Formulations are: 50 or 82.5% EC, 5% dust, 40% WDP and 5% Gr. Suitable formulations for application at ultra low volume rates are also available.

Fensulfothion

Fensolfothion ($C_{11}H_{17}O_4PS_2$) is diethyl 4-(methyl sulphinyl) phenyl phosphorothionate or 0,0-diethyl-O- (4-methylsulfinyl-phenyl) -monothiophosphate. It is a yellowish brown liquid, soluble in most organic solvents. Its acute oral and dermal LD_{50} for rat are 2 to 11 and 3 to 30 mg/kg respectively. It is a systemic and contact poison with very long residual effect. It is a nematicide and insecticide. It is applied to the soil in granular formulation for the control of free-living, cyst and root-knot nematodes, and soil-inhabiting larvae of Lepidoptera, Diptera and Coleoptera. Its systemic action effects control of sucking and biting insects on different crops. Formulations: 5 or 10 % granule.

Fenthion

Fenthion ($C_{10}H_{15}O_3PS_2$) is dimethyl 3-methyl-4-methylthiophenyl phosphorothionate or 0,0-dimethyl-0-4-methylmercapto-3-methyl-phenyl)-thiophosphate. It is a colourless oily liquid, sp. gr. 1.25; practically insoluble in water (54 to 56 mg/litre), limited solubility in petroleum ether and readily soluble in most organic solvents. Its acute oral and dermal LD_{50} for rat are 200 and 1300 mg/kg respectively. It is a contact and stomach poison possessing depth action and long residual effect. It is a broad spectrum insecticide particularly effective against fruit-flies, leafhoppers, cereal bugs, rice stem borers and mango nut weevil. It is also used in the control of mosquito larvae and bed bugs. It is harmful to bees. It may be phytotoxic on sensitive cotton and apple varieties such as "golden" or "delicious."

Formulations are: 50 or 82.5 % emulsifiable concentrate, ULV formulation, 5 per cent dust and 20 % EC for use in the control of pests of public health.

Formothion

Formothion ($C_6H_{12}O_4PS_2N$) is S-(N-formyl-N-methyl carbamoylmethyl) dimethyl phosphoro-thiolothionate or O,O-dimethyl S-(N-methyl-N-formyl-carbamoyl-methyl-dithiophosphate. It is a yellowish viscous oil or crystalline solid with a faint characteristic smell. Its acute oral and dermal LD_{50} to rat are 400 and 400 to 1680 mg/kg respectively. It is a systemic insecticide and acaricide with contact action, effective against various sucking insects and mites on crops. Formulated as 25 % emulsifiable concentrate.

Malathion

Malathion ($C_{10}H_{19}O_6PS_2$) is S-l,2-di (ethoxycarbonyl) ethyl dimethyl phosphoro-thiolothionate or 0,0-dimethyl S- (1,2-dicarbethoxyethyl) phosphorodithioate. It is a brownish liquid. The technical material is 95 to 98 per cent pure with an unpleasant odour. Its specific gravity at 25° C is 1.23, soluble in water to 0.0145 %, slightly soluble in mineral oils and soluble in most organic solvents. It is unstable in alkaline medium. It is one of the safest chemicals available, its acute oral and dermal LD_{50} to rat being 1400 to 1900 and 4000 mg/kg respectively. At the recommended dosages it can be applied to most edible crops within one to three days of harvest without danger of excess harmful residues. It is a contact and stomach poison used for the control of a wide variety of pests of crops such as aphids, hoppers, psyllids, plant bugs, aleyrodids, flea beetles, grey weevils, caterpillars, hispa, mealy bugs and scales, thrips, etc. and red mites on arecanut. In public health it is used in out-door and residual sprays for the control of mosquitoes, in breeding sites for the control of flies and in households for the control of bed bugs. In animals it is quite useful for the control of lice, fleas, ticks and mites infesting cattle, chicken, goat, sheep and dogs. Formulated as 50 % EC, 25 % WP, 5 % dust, 10 % granule and 0.25% spray. Malathion low volume concentrate formulation containing 96 % active ingredient is applied undiluted with water for the control of pests of paddy, cotton, wheat, redgram, sugarcane, vegetables, millets, etc. and for the control of grasshoppers and locusts. Granular malathion is recommended at 1.5 kg active ingredient per hectare for the control of borers of sorghum and *Pennisetum typhiodeum.*

Methyl Parathion

Methyl parathion ($C_8H_{10}NO_5PS$) is 0,0-dimethyl-O-nitrophenyl phosphorothionate. It is less toxic to mammals but highly toxic to insects than parathion. LD_{50} for rat: oral 14-24 mg/kg, dermal 67 mg/kg. It is used against a wide range of pests of crops. Formulations registered are 2% dust and 50% EC.

Monocrotophos

Monocrotophos ($C_7H_{14}O_5NP$) is dimethyl *cis*-1-methyl-2-methylcarbamoylvinyl phosphate or *cis*-(2-methylcarbamoyl-1-methylvinyl)-dimethylphosphate or dimethyl phosphate of 3-hydroxy-N-methyl-*cis*-crotonamide. It is made up of colourless crystals with mild ester smell, miscible with water, acetone and alcohol; sparingly soluble in xylene and very sparingly soluble in kerosene and diesel fuel. It is rapidly hydrolysed in alkaline solutions than in acids. It is a hazard to wild life if the food is contaminated with residues above 0.5 ppm. It is toxic to bees and at normal application rates it appears to be safe for fish and oysters. It is a systemic insecticide as it is absorbed by the plant roots and is translocated in the xylem into stems and leaves. It acts as a stomach and contact poison. Three major pathways are recognised in the metabolism of monocrotophos in plants and animals. These are hydrolysis at the vinyl-phosphate bond; at the methyl-phosphats bond and an oxidative process, the latter giving rise to N-hydroxymethyl amide and the unsubstituted amide of monocrotophos, which are comparable to those of the parent compound in their toxicities. In certain varieties of cherry and some varieties of sorghum it causes scorching of the edges of leaves. Its acute oral LD_{50} for rat is approximately 20 mg/kg. Dermally, the LD_{50} for rabbits is 342 (154–760) mg/kg. It is not an eye-irritant.

It is effective against thrips, aphids, aleyredids, leaf miners, cotton bollworms, leaf webbers, and a number of other in sect pests and mites of crops. Formulation: 36%SL.

Oxydemeton-Methyl

Oxydemeton ($C_6H_{15}O_4PS_2$) is S -(2-ethyl-sulphinyl) ethyl dimethyl phosphorothiolate or 0, 0-dimethyl-S-2-(ethyl sulphinyl) ethylthio-phosphate. It is a yellowish liquid, odourless, miscible with water, soluble in most organic solvents and practically insoluble in petroleum ether. It is unstable in an alkaline medium. It is a systemic insecticide effective against sucking insects and mites. It is very largely harmless to parasites and predators but harmful to bees. Its acute oral and dermal LD_{50} for rat are 57 and 100 mg/kg respectively. Formulated as 25 % EC.

Phenamiphos

Phenamiphos, $C_{13}H_{22}NO_3PS$, is O-ethyl-O-(3-methyl-4-methylthio-phenyl)-isopropyla mido-phosphate; or lsopropyl-phosphoroamidic acid-O-ethyl-(3-methyl-4-methyl-thiophenyl)-ester. It is a white crystalline material; solubility 700 ppm in water at 20°C; slightly soluble in organic solvent besides petroleum ether. It is a systemic nematicide effective against root-knot nematodes, cyst-forming nematodes and free-living nematodes. It also controls sucking insect pests and spider mites. When applied to foliage it is translocated basipetally to the roots, kill nematodes living in the roots, and protects the plants against further nematode infestation. Its formulated as 5 and 10% granule and 40% EC. Its acute oral LD_{50} for rat is 15.3 to 19.4 mg/kg, dermal 500 mg/kg.

Phenthoate

Phenthoate is S-*alpha*-ethoxycarbonylbenzyl dimethyl phosphorothiolothionate or O,O-dimethyl S-*alpha*-ethoxycarbonylbenzyl phosphorodithioate or ethyl ester of O,O-dimethyl-dithiophosphoryl *alpha*-phenyl acetic acid or ethyl mercaptophenylacetate O,O-dimethyl phosphorodithioate. The pure compound is of colourless crystals with light aromatic odour. The technical material containing 90 to 92 % phenthoate is an oily liquid, reddish yellow, aromatic. Its acute oral and dermal LD_{50} for rat are 200 to 300 and 700 to 1400 mg/kg respectively. It is a wide spectrum insecticide and acaricide, effective against lepidopterous borers and leaf feeders, sucking insects, sawfly larvae, etc. and tetranychid and eriophyid mites. It is effective for the control of mosquito larvae at concentrations lower than those found to be toxic to fish and also for adults. It can also be used for the control of external mites and insects on domestic animals. It is phytotoxic on some vine, peach and apple varieties.

The metabolism of phenthoate in plant tissues comprises of oxidation and hydrolysis. Oxidation results in oxygen homolo gue of phenthoate, which is insecticidally active. Hydrolysis results in inactive products among which phosphoric, dimethylphosphoric and monomethyl phosphoric acids have been identified. At recommended dosages it does not leave any harmful residues in edible parts of plants. Formulated as liquid containing 50 % active ingredient; oil formulation containing 5 % active ingredient and 80 % mineral oil (UR 89 per cent); wettable powder containing 40 % a.i., powder containing 3 % a.i. and granule containing 2 % a.i.

Phorate

Phorate ($C_7H_{17}O_2PS_8$) is diethyl S-(ethyl-thiomethyl) phosphorothiolothionate or O, O-diethyl S-(ethylthio) methyl phosphorodithionate. The technical grade containing not less than 90 % phorate is a clear mobile liquid. It has low solubility in water, approximately 50 ppm, but miscible in xylene, vegetable oils, carbon tetrachloride, alcohols, ethers and esters. It gets hydrolysed in the presence of moisture and alkaline conditions. It is a systemic insecticide and is absorbed by roots and subsequently translocated to aerial parts of the plant. When absorbed by plants phorate is initially and rapidly oxidised to its insecticidally active sulfoxide and sulfone: which in turn are converted to sulfoxide and sulfone of the phorate oxygen analogue. These active compounds on hydrolysis are broken down to various inactive thio- and phosphoric acids and esters. It has also contact and fumigant action. In addition to being an insecticide it has also shown some nematicidal and acaricidal action. Its LD_{50} oral and dermal for rat are 16-37 and 2.5-6.2 mg/kg respectively. It has been found useful in the control of sorghum shootfly, aphids on groundnut and potato, sucking pests of cotton, tobacco and vegetables, sucking insects and gallmidge on rice, etc. Granules containing 10 % phorate is applied, depending on the crop, before planting or sowing, at planting or sowing or transplanting or after transplanting.

Phosalone

Phosalone, $C_{12}H_{15}ClNO_4PS_2$, is O,O-diethyl-S-(6-chloro-l.3 benzoxazol-2 (3H)-onyl-methyl) phosphorodithioate; (or) O,O-diethyl S-(6-chlorobenzoxazolinyl-3-methyl) dithiophosphate; (or) 3-O, O-diethyl dithiophosphorylmethyl-6-chlorobenzoxazolone. It is a white crystalline substance with alliaceous or garlicky odour; practically insoluble in water, but highly soluble in many organic solvents. It is relatively stable in acid medium but rapidly hydrolysed in alkaline medium to the principal products 6-chlorobenzoxazolone, diethylthio-phosphoric acid, and formaldehyde. It is oxidized to the relatively unstable 0,0-diethyl S-(6-chlorobenzoxazolmyl-3-methyl) thiophosphate, which is assumed to be the first metabolite of phosalone in plants and it quickly breaks down.

Phosalone is also rapidly degraded in animal tissues. Its acute oral LD_{50} for rat is 135 mg/kg, dermal 1500mg/kg. It is recommended for the control of insect pests of various crops and mites. Treatment of seeds with phosalone also affords protection to seedlings from damage by insects and mites. It is moderately toxic to bees. It is formulated as 35 % EC, 30 % WP, 2.5 % and 4 % dust.

Phosphamidon

Phosphamidon ($C_{10}H_{19}O_5NClP$) is 0-(2- chloro-2-diethyl-carbamoyl)-1-methylvinyl) - 0, 0-dimethyl phosphate (or) 0,0-dimethyl-0-(l-methyl-2-chloro-2-diethyl-carbamoyl-vinyl) phosphate (or) 0,0-dimethyl-0-(diethylamido-l-chloro-crotonyl-2) phosphate or O-(1-chloro-l-diethyl-carbamoyl-1 -propen-2-yl)-0,0-dimethyl phosphate (or) 2-(0,0-dimethyl phosphoryloxy)-l-chlorocrotonic acid diethylamide. It is colourless to pale yellow with faint, pleasant odour. Technical grade is dark brown and commercial product is bright violet due to addition of a dye. It is miscible in water and all organic solvents except saturated hydrocarbons in which it is soluble only to a limited extent. Technical grade contains 92 % pure. The insecticidal activity of phosphamidon is mostly due to its β-isomer and the isomers α and β are found in the ratio of 3:7. Technical grade phosphamidon is very stable. It is a systemic insecticide and acts as a stomach poison, and has a relatively low contact action. Metabolism of phosphamidon gives to desethylphosphamidon, which is roughly as toxic as the parent compound, and is rapidly broken down by the plant. Phosphamidon is of relatively very low toxicity to fishes but toxic to bees. It is phytotoxic on some cherry varieties. It corrodes iron, tin plate and aluminium. Its acute oral and dermal LD_{50} values for rat are 15 and 125 mg/kg respectively. It is effective against many sucking, chewing and mining insects and certain mites. It is widely used for the control of yellow borer and other sucking pests of rice. Formulation: 50% SL.

Pirimiphos-methyl

It is O-(2-diethylamino-6-methylpyrimidin-4yl) O,O-dimethyl phosphorothioate. Its acute oral LD_{50} for rat is – oral >2000 mg/kg, dermal 4592 mg/kg. It is a fast acting broad spectrum insecticide effective against wide range pests of stored grains. It finds use in household pest control as 1% spray or 2% acrosol.

Profenofos

It is an insecticide and acaricide. Chemically it is O-4-bromo-2-chlorophenyl O-ethyl S-propyl phosphorthioate. Technical grade solution is an amber coloured liquid with garlic-like odour. It is readily miscible with organic solvents. Its acute oral LD_{50} for rat is

358 mg/kg; dermal for rabbit 277 mg/kg. It is registered as 50% EC and controls a wide range of pests at 500 g a.i./ha.

Propetamphos

It is (E)-O-2-isopropoxycarbonyl-1-methylvinyl O-methyl ethylphosphoramidothioate. Its acute LD_{50} for rat - oral 119 mg/kg, dermal 2825 mg/kg. It is a contact insecticide with stomach action. It is used for control of public health pests such as cockroaches, flies, fleas, mosquitoes, etc. as 1% spray.

Quinalphos

Quinalphos ($C_{12}H_{15}N_2O_3PS$) is O, O-diethyl-O-(quinoxalinyl (2)) -thionophosphate. It is an odourless white crystalline solid. Its solubility in water is 22 ppm at 24° C, but readily soluble in methyl and ethyl alcohol, ethyl ether, acetone, ketones, and aromatic hydrocarbons such as benzene, toluene, xylene, etc. It is hydrolysed in alkaline medium. Its acute oral LD_{50} for male rat is 137 mg/kg and dermal 1400 mg/kg. It is an insecticide effective against a wide spectrum of insect pests of crops. It is an effective acaricide too. It is formulated as 25% EC, 1.5% dust and 5% Gr.

Temephos

It is O,O'-thiodi-4,1-phenylene-O,O,O'O'-tetramethyl phosphorothioate. Its acute oral LD_{50} for rat is 4204 mg/kg (male), 10000 mg/kg (female), dermal (rabbit) 2000 mg/kg (male), 2378 mg/kg (female). It finds use as a mosquito and midge larvicide.

Thiometon

Thiometon ($C_6H_{15}O_2PS_3$) is S-2-(ethylthio) ethyl dimethyl phosphorothiolothionate or O, O-dimethyl-S-ethyl mercaptoethyl-dithiophosphate. It is a systemic insecticide effective against aphids and other sucking insects, sawflies and mites. Its acute oral and dermal LD_{50} to rat are 100 and 200 mg/kg respectively. It is formulated as 25% EC.

Trichlorphon

Trichlorphon or Trichlorfon ($C_4H_8Cl_8O_4P$) is dimethyl 2,2,2-trichloro-l-hydroxyethyl phosphonate or 0,0-dimethyl-(2,2,2-trichloro-l-hydroxyethyl phosphonate). It is a white crystalline powder. It is soluble in water but readily soluble in low alcohols, ketones, aromatic hydrocarbons, chlorinated hydrocarbons (methylene chloride, chloroform) and dimethyl sulphoxide. It is insoluble or very slightly soluble in carbon tetrachloride, petroleum ether, ligroin and cyclohexanone. It is a contact and stomach poison with some fumigant action. It has penetrating effect also. Under natural conditions it is readily dehydrochlorinated to dichlorvos. It is a quick acting chemical effective against Lepidoptera, Diptera and Hemiptera. It has a lower order of toxicity to bees and it should not be used on apples until four weeks after blossom otherwise may result in leaf and fruit drop. It is also used in baits. Its acute oral and dermal LD_{50} for rat are 650 and >5000 mg/kg. Formulated as 80 % soluble powder, 5 % granular and 5 % dust. It is used in baits containing 100 g of active ingredient (soluble powder), 10 kg of bran, 500 g of sugar or 1 kg of molasses in 8 to 10 litres of water for the control of cutworms. Bait sprays consisting of the active ingredient and protein hydrolysate are useful for the control of fruit-flies. Granule is used for the control of borers of maize and sugarcane.

4.3.5 Carbamates

Carbamates are derivatives of carbamic acid and have an – OCON== group in the molecule. Development of carbamate insecticides has been receiving the attention of chemists for the past 15 to 20 years as a result of which some are now on the market. The carbamates that were first marketed are isolan, a systemic insecticide, and dimetilan, a stomach poison, which belong to N,N-dimethyl-carbamates. These were followed by the N-methylcarbamates of which carbaryl has become one of the most widely used broad spectrum insecticides. The others include products like propoxur (arprocarb), methiocarb, Zectran, etc. Insecticides and acaricides are also found in carbamates such as aldicarb. Some may be found useful in the control of nematodes and snails. The carbamate esters inhibit acetylcholinesterase in insects and mammals.

The insecticidal carbamates are derivatives of carbamic acid and dithiocarbamic acid.

Derivatives of Carbamic acid

They are classified into three classes viz. heterocyclic carbamates, phenyl carbamates and oxime carbamates.

Heterocyclic Carbamates

Isolan: Isolan is a product containing l-isopropyl-3-methyl-5-pyrazolyl dimethylcarbamate or 1 -isopropyl-3-ethylpyrozolyl-(5) N,N-dimethyl carbamate. It is a systemic insecticide effective against aphids and has been used in fly baits. Its acute oral and dermal LD_{50} to rat being 12 and 35 to 60 mg/kg, respectively.

Pyrolan: Pyrolan is a product containing l-phenyl-3-methyl-5-pyrazolyl dimethylcarbamate. Its acute oral LD_{50} to rat is 50 to 90 mg/kg.

Dimetilan: Dimetilan is 2-dimethylcarbamoyl-3-methyl-5- pyrazolyl dimethylcarbamate and found use in fly baits. Its acute oral and dermal LD_{50} to rat are 25 to 50 and 600 to 700 mg/kg respectively.

Other compounds include Pirimicarb, Dimefan and Dimetan.

Phenylcarbamates

Carbaryl

Carbaryl is l-naphthyl N-methylcarbamate. Its insecticidal properties were first described by H. L. Haynes* and his associates and introduced in 1956. It is a white crystalline solid. The technical material is 95% pure. Its solubility in water is 0.004 %, and is soluble in solvents such as xylene, methyl isobutyl, ketone, petroleum ether and carbon tetrachloride. It is a non-specific insecticide effective against a wide spectrum of pests including those that are resistant to chlorinated hydrocarbon insecticides. It is a contact and stomach poison and has a longer residual action. Its acute oral and dermal LD_{50} to rat are 400 and >500 mg/kg respectively. Dust containing 2.5 % carbaryl is used in the control of human lice and dandruff and cattle lice. Ticks of cattle, sheep and dogs and mites and lice of poultry are controlled by 5% carbaryl dust. In the control of pests of crops it is effective against pests of cotton, red palm weevil on coconut, pests of vegetable crops, etc. Formulations are: Dusts containing 2.5, 5 or 10 % carbaryl, 85 SP, 50 WP, 24 % emulsive concentrate and 4 % granule. Granule containing 4 % each of carbaryl and gamma HCH is effective against pests of rice and sugarcane.

Propoxur

Propoxur is 2-isopropoxyphenyl N-ethylcarbamate. It is a white to cream-coloured crystalline powder with a mild phenolic odour. Its solubility in water is about 0.2 % but readily soluble in organic solvents. A broad spectrum insecticide effective in controlling household and public health pests. It is a contact and stomach poison, brings about rapid knock down and has a long residual action. Its acute oral and dermal LD_{50} to rat are 83 to 175

* *Contrib. Boyce Thompson Inst.*, 1957, 18 : 507

and > 1000 mg/kg respectively. Formulations are: 20 % EC, 1% or 2% aerosol and1% spray in hotels, bakeries, factory buildings, warehouses, storerooms, schools, military barracks, stables, ships, aircraft, etc. for the control of cockroaches, crickets, flies, etc.

Carbofuran

Carbofuran ($C_{12}H_{15}NO_3$) is 2,3-dihydro-2,2-dimethyl 7 benzofuranyl methyl carbamate. It is a white crystalline solid with slightly phenolic odour. It is noninflammable and unstable in alkaline media. It is a reversible cholinesterase inhibitor capable of causing systemic toxic effects when inhaled or ingested. Its acute oral and dermal LD_{50} to rat are 8.2 to 14.1 mg/kg and 10,200 mg/kg respectively. It is effective against sucking pests, thrips, mites and soil-inhabiting pests such as corn rootworms, flea beetle larvae, white grubs, maggots and nematodes. Established crop tolerances are 0.5 ppm in forage, 0.1 ppm in grain, and 0.2 ppm in rice and rice straw. Formulation available in India is 3% Gr.

Carbosulfan

Carbosulfan is 2,3-dihydro-2,2-dimethyl benzofuran- 7-yl (dibutylaminothio)-methyl carbamate. It is effective against a broad spectrum of pest species on various crops. It is metabolized in plants to carbofuran and 3-hydroxycarbofuran. Its acute oral and dermal LD_{50} for rat are respectively are 185-250 mg/kg and >2000 mg/kg. Its registered formulations are 25% DS and 25% EC. Seed treatment with 25DS 50 g/kg delinted seed of cotton effectively controls sucking pests up to 40 days after sowing. Foliar spray with 25% EC at 400-500 g a.i./ha controls the sucking pests on cotton.

Oxime Carbamates

These N-methyl carbamic acid derivatives are the esters of the oximes of aliphatic and cyclic aldehydes and ketones. They are reported to be effective against insects, mites and nematodes.

Aldicarb

Aldicarb, $C_7H_{14}N_2O_3S$, is (methylthio) propionaldehyde 0-1-(methyl-carbamoyl) oxime. It is a systemic insecticide, acaricide and nematicide, effective against a wide spectrum of insects and mites and nematodes. It is formulated as a 10 % granule intended only for soil application. In plants it is rapidly absorbed and oxidised to the principal toxicant aldicarb sulfoxide, which is further oxidised to the less toxic aldicarb sulfone. The rapid uptake of aldicarb and systemic movement of its metabolites in plant is attributed to their relatively high solubility in water. Its acute oral LD_{50} to rat is 6.2 mg/kg and dermal 3200 mg/kg. It was in use for the control of golden nematode of potatoes on the Nilgiris.

Methomyl

It is a product containing S-methyl-N- [(methylcarbamoyl) oxy] thioacetamidate. It is a white crystalline solid with a sulfurous odour. Its acute oral LD_{50} for rat is 17 mg/kg (male), 24 mg/kg (female); dermal (rabbit) >2000 mg/kg. It has broad spectrum control of insects of a wide variety of crops. It is effective against cabbage looper, imported cabbageworm and Diamondback moth and cotton bollworms at 300-450 g a.i./ha. Registered formulation in India is 40% SP.

Thiodicarb

Thiodicarb is Dimethyl N,N-(thiobis(methylimino)carbonyloxy)bis(ethanimidothioate). Empirical formula is $C_{10}H_{18}N_4O_4S_3$. It is an insecticide with ovicide action and active against major lepidopterous pests. Its acute oral LD_{50} for rat is 160 mg/kg; dermal (rabbit) >2000 mg/kg. As seed treatment rapidly gets translocated systemically through plants. Also acts as a moluscicide causing paralysis and death. It is registered as 75% WP and recommended at 0.75 kg a.i./ha for control of bollworms on cotton.

Oxamyl

Oxamyl is methyl N', N'-dimethyl-N-[(methyl-carbamoyl)oxy]-l-thiooxamidate. It is formulated as 25.2% EC and 10% granule. It is effective against insects, mites and nematodes and has systemic action. When applied to the foliage, gets translocated to the roots and controls nematodes in some crops. Its acute oral LD_{50} to rat is 5.4 mg/kg.

Derivatives of Dithiocarbamic Acid

Carbothion

It is Sodium N-methyldithiocarbamate. It is a nematicide and formulated as 40 % EC and the dosage is 250 to 1000 kg/ha applied three weeks prior to planting. Its nematicidal action is attributed to the breakdown product methyl isothiocyanate. Its acute oral LD_{50} to rat is 820 mg/kg.

4.3.6 Organic Sulphur Compounds

These are compounds, which are effective against mites on crops and ticks on animals and are called acaricides. A number of them are inactive against insects. Certain compounds are exclusively ovicides and may kill the newly emerged nymphs, the others kill all stages of mites. These are in general stable and possess long residual action and low mammalian toxicity.

Tetradifon

Tetradifon, $C_{12}H_6CI_4O_2S$ is 2,4,5,4 tetrachiorodiphenyl sulphone. It is a crystalline solid insoluble in water and its melting point is 148°C. It is stable in alkali and acid media, light and temperature. It possesses a very prolonged residual action. Its acute oral LD_{50} to rat is >5000 mg/kg; dermal LD_{50} to rabbit is 10,000 mg/kg. It is effective against all stages of mites. It is not toxic to bees and does not taint the treated plants if applied at concentrations of 0.1 to 0.2 %. The formulation 8% EC was recommended for the control of tea mites but presently its use in India has been withdrawn.

Propargite

Propargite is 2-(4-tert-butylphenoxy) cyclohexyl prop-2-ynyl sulfite. Empirical formula: $C_{19}H_{25}O_4S$. It is a light to dark brown liquid and miscible with organic solvents such as acetone, toluene, methanol, dichloromethane and hexane. It is an acaricide effective against mites on a wide range of crops and fruit trees. Its acute oral LD_{50} for rat is 2800 mg/kg; dermal (rabbit) >4000 mg/kg. It is relatively safer to bees and other beneficial insects. Propargite 57% EC has been found effective against mites on tea, chillies, apple, etc.

4.3.7 Synthetic Pyrethroids

Allethrin was the first synthetic analogue of pyrethrum developed in 1949 by Green and La Forge. The other compounds subsequently synthesised were furethrin, barthrin, tetramethrin, cyclethrin, resmethrin, bioresmethrin, etc. The following synthetic pyrethroid compounds have received greater attention in India.

Allethrin

Allethrin, $C_{19}H_{26}O_3$, is the common name for (*RS*) -3 -allyl-2 methyl-4 oxocyclopent - 2 enyl (*1RS*) -*cis, trans* chrysanthemate. It was first described by M. S. Schechter *et al.* in

1949 and introduced by Sumitomo Chemical Co. It has contact, stomach and respiratory action and brings about quick knockdown of flies and mosquitoes when applied in combination with synergists like piperonyl bitoxide. The acute oral LD_{50} for rat is 585- 1100 mg/kg; dermal for rat > 2000 mg/kg. Its registered formulations are 0.5%, coil, 2% and 4% mat, 0.5% aerosol and 3.6% L.

d-Allethrin

It is (*RS*) – 3 allyl - 2 methyl - 4 -oxocyclopent - 2 - enyl (*IR*) *cis, trans* chrysanthemate. It has been registered mainly as 2% and 4% mat and 1% coil for control of mosquitoes. Its acute oral LD_{50} for rat is female 900 mg/kg, male 2150 mg/kg; dermal for rabbit > 2000 mg/kg. Each mosquito mat, which is ready to use, contains 4% *d*-allethrin w/w. The mat is required to be heated in an electric heater device sold for the purpose. Consequent to the rise in temperature of the heater the insecticide is vapourised and vapours are released to the air for a period of seven to eight hours. For better results close the doors and windows for 30 minutes initially after switching on the device. The mat is to be changed every night. Products available are 0.1% coil – green or red, 0.5% coil, 0.2% coil and 2% + PBO 2% mat.

Alphacypermethrin or Alphamethrin

Alphamethrin, $C_{22}H_{19}C_{12}NO_3$, is a pyrethroid insecticide with contact and stomach action. It is effective against a wide range of chewing and sucking insects of agricultural crops, insects of public health and ectoparasites of animals. Acute Oral LD_{50} for rat is 64 mg/kg; dermal for rabbit > 2000 mg/kg. The formulation registered is 10% EC. It is recommended for control of cotton bollworms at 25-35 g a.i./ha. Alphamethrin 5% WP finds use in pubic health pest control.

Cyfluthrin

Cyfluthrin, $C_{22}H_{19}CI_2NO_3$, is Cyano (4-fluoro-3-phenoxyphenyl)methyl 3-(2,2-dichloroethenyl)-2,2 dimethylcyclopropanecarboxylate. It is a contact and stomach poison with rapid knockdown and long residual action. Controls many pests of crops, and pests of public health, veterinary and stored product importance. Acute oral LD_{50} for rat is 500 mg/kg; dermal for rat > 5000 mg/kg. Formulation registered is 10% EC and recommended at 12.5-18.0 g a.i./ha. For public health pest control 10% WP and 5% EW have been registered in India.

Cypermethrin

Cypermethrin is the common name for (*RS*) cyano- 3 -phenoxybenzyl (*1RS)-cis, trans* -3-(2,2 – dichlorovinyl)-2,2-dimethyl cyclopropanecarboxylate. The *cis/trans* ratios may vary with manufacturing process. M. Eliott *et al.* (1975) discovered it. It is a stomach and contact insecticide effective against lepidopterous larvae affecting various crops particularly bollworms and leaf eating caterpillars of cotton. Its acute oral LD_{50} for rat is 250 mg/kg (corn oil), 4123 mg/kg (aqueous suspension). It is relatively toxic to honey bees. Formulations: 10% EC and 25%EC. For household pest control cypermethrin 1% chalk, cypermethrin 0.1% aqueous HH and cypermethrin 0.11% + pyrethrum 0.02% + PBO 1% aerosol have been registered.

Cyphenothrin

It is (RS)á-cyano-3-phenoxybenzyl (1R)-cis,trans-chrysanthemate. Its acute LD_{50} for rat – oral 318 mg/kg (male), 419 mg/kg (female), dermal >5000 mg/kg. It is an insecticde for control of flying and crawling insects in household, industrial areas and outdoor use.

Deltamethrin

Deltamethrin is the common name for (*S*) S-cyano-3 phenoxybenzyl (*1R*)-*cis* - 3- (2,2 - dibromovinyl) - 2,2-dimethyl cyclopropanecarboxylate. M. Elliott *et al.* (1974) described it and it was introduced by Roussel Uclaf. It is an effective contact and stomach poison against a wide range of insects and recommended at a dosage varying from 12.5 to 15 g a.i./ha. It is stable on exposure to air and sunlight. It is also recommended for the control of mosquitoes and animal ectoparasites. Its acute oral LD_{50} for rat is 135 mg/kg and dermal for rabbits > 2000 mg/kg. It is toxic to fish and honeybees. Formulations are: 2.8% w/w EC (250 g a.i./litre), 0.02% spray, 2.5% Flow, 2.5% WP, 0.5% Chalk and tablet; deltamethrin 2.5% + *d*-allethrin 2% EC and deltamethrin 0.05% + allethrin 0.04% aerosol.

d-Phenothrin

It is 3-phenoxybenzyl (1R)-cis-trans-chrysanthemate. Its acute LD_{50} for rat – oral >10000 mg/kg, dermal >10000 mg/kg. It finds use in control of stored grain pests and flying and crawling insects in household and industrial locations.

Etofenprox

Etofenprox, $C_{25}H_{28}O_3$, is a non-ester pyrethroid introduced in 1987. It is a contact and stomach insecticide. Its acute oral LD_{50} for rat is 42880 mg/kg; dermal for rat > 2140 mg/kg. It is effective against pests of rice, particularly BPH and leafhoppers at 50 g a.i./ha. It is also effective against houseflies and cockroaches. Its registered formulation is 10% EC.

Fenpropathrin

Fenpropathrin is (RS) á-cyaano-3-phenoxybenzyl 2,2,3.3-tetramethyl-cyclopropanecarboxylate. It is yellow brown liquid or solid soluble in common organic solvents. Its acute oral LD_{50} for rat is 66 mg/kg; dermal (rabbit) >2000 mg/kg. It is an acaricide and insecticide effective against lepidopterous larvae, aphids, whiteflies, mites, etc. on various horticultural and agricultural crops. It also controls mosquitoes. Formulation is 2.4 EC.

Fenvalerate

Fenvalerate is the common name for (*RS*)- cyano - 3 - phenoxybenzyl (*RS*) - 2 - (4-chloro phenyl) - 3 methylbutyrate. It was first reported by N. Ohno *et al.* (1974). It is a contact insecticide effective against leaf-eating caterpillars and cotton bollworms. It is stable in sunlight and has longer residual toxicity. Also useful in the control of public health insects and animal ectoparasites. Its acute oral LD_{50} for rat is 300-630 mg/kg; in rabbits moderate skin and eye irritation has been observed. Formulations are: 20% EC and 0.4% DP. Effective against a wide range of pests at 60-75 g a.i./ha.

Lambda-Cyhalothrin

Lambda – cyhalothrin, $C_{23}H_{19}ClF_3NO_3$, chemically á-cyano-3-phenoxybenzyl 3-(2-chloro-3,3,3-trifluoro-prop-1-enyl)-2,2-dimethylcyclopropanecarboxylate is a 1:1 mixture of the (Z)-(1R, 3R), S-ester and (Z)-(1S,3S), R-ester. It is a contact and stomach insecticide and acaricide with quick knock-down and long residual action. Its acute oral LD_{50} for rat is 79 mg/kg (male), 56 mg/kg (female); dermal 632 mg/kg (male), 696 mg/kg (female). It is effective against a wide range of pests of agriculture and public health importance. Its registered formulations are 5% EC, 10% WP and 0.5% chalk. Formulation 5% EC recommended for control of pests of groundnut, rice, onion, etc. at 12.5-25.0 g a.i./ha.

Permethrin

Permethrin is 3-phenoxy benzyl (*1RS*) *cis, trans*-3(2,2,dichlorovinyl)-2,2 dimethyl cyclopropane-carboxylate. The ratio of *cis-trans* isomers may vary with manufacturing process. It was discovered by M. Elliot *et al.* (1973)*. It is a contact insecticide effective against a large number of insect pests particularly lepidopterous larvae at 100-150 g

* *Proc. Br. Insectic. Fungic. Conf.* 7 th, 1973, **2:** 721.

a.i./ha. It also finds use in the control of ectoparasites of animals and public health and household pests. Its acute oral LD_{50} varies with the *cis/trans* ratio of the technical material. For 40:60 ratio the values are: oral for rat is 430 to > 4000 mg/ kg. Formulations are: 25 EC and 5% in smoke generator.

Prallethrin

Chemically it is (S)-2-methyl-4-oxo-3-(2-propynyl)-cyclopent-2-enyl (1R)-*cis-trans*-chrysan-the-mate. It is yellow to yellow-brown liquid miscible with most organic solvents. Its acute oral LD_{50} for rat is 640 mg/kg (male), dermal >5000 mg/kg. It is effective against flying and crawling insects in household. It finds use in aerosols, emulsifiable concentrate, mosquito coil/mat, vapouriser liquid, and oil liquid. Prallethrin 0.04% and 0.05% mosquito coils, Prallethrin 0.5% mat, 1% blue or red mat, 1.2% mat, 0.8% or 1.6% LV (liquid vapourizer) have been introduced.

4.3.8 Six-membered Heterocyclic Compounds

Certain compounds with six atoms in the ring are known to have specific biological activity and among them coumarin has been found to be a promising rodenticide. Derivatives of coumarin have blood anticoagulant properties and, therefore, when systematically introduced into their food they cause internal bleeding and death of the rodents.

Bromodiolone

It is a coumarin anticoagulant. Empirical formula $C_{30}H_{23}BrO_4$. Chemically it is 3-[3-(4'bromo [1,1'biphenyl]-4yl)-3-hydroxy-1-phenyl-propyl]-4-hydroxy-2H-1-benzopyran-2-one. It is registered as 0.25% concentrate bait, 0.005% ready to use bait and 0.005% ready to use bait cake. It is a single dose anticoagulant rodenticide and causes haemorrhage in the blood system. It ensures destruction of the insect in four to five days. The cake is to be placed near to burrow / places frequented by rats and no pre-baiting is necessary. No bait shyness is noticed.

Coumatetralyl

Coumatetralyl, $C_{19}H_{16}O_3$, is 3 (α-tetralyl) 4-hydroxycoumarin. It is more toxic to rats than warfarin and coumachlor. Powder containing 0.75 % active material is sprinkled in hiding places and on rat runways. One part of the powder may be mixed with 19 parts of bait material and used. It blocks prothrombin formation in the liver resulting in inhibition of blood coagulation. Multiple feeding is essential. No bait shyness is observed.

Coumachlor

Coumachlor is 3-(α-acetonyl) 4-chlorobenzyl)-4-hydroxycoumarin. It is also useful as a rodenticide. Registered as 0.5% concentrate bait and 0.025% ready to use bait.

Warfarin

Warfarin, $C_{19}H_{16}O_4$, is 3-(α-acetonylbenzyl)-4- hydroxycoumarin. It is used for the control of rats in baits as 0.025 % ready to use bait or 0.5% concentrate bait. The animal has to be fed with the poison at least for four or five times in the course of several days to obtain effective mortality of rats. It is an anticoagulant rodenticide. It causes internal bleeding by causing reduction of the prothrombin content of the blood.

4.3.9 New Classes of Compounds including Fermentation Products

In the recent years a number of new classes of compounds have been introduced for pest control and a number of them have been registered for use. Some such new compound which are under development and those which are registered in India are listed below. The Insect Growth Regulators (IGR) have been listed under the chapter Insect Growth Regulators.

Abamectin

An insecticide *cum* acaricide having a mixture containing ≥ 80 % avermectin B1a and ≤ 20% avermectin B1b. It has contact and stomach action. It is effective against mites and leaf miners on vegetables, citrus, etc. It stimulates release of γ-aminobutyric acid, an inhibitory neurotransmitter, which causes paralysis in insects. Acute oral LD_{50} for rat 300 mg/kg and dermal for rabbit > 2000 mg/kg. It is toxic to bees. No bioaccumulation in environment has been reported. Found effective against mites on roses in polyhouses and diamond back moth on cabbage. Formulation: 1.9 % EC.

Acetamiprid

Acetamiprid, $C_{10}H_{11}ClN_4$, is (E)-N^1-(6-chloro-3-pyridyl)methyl)-N^2-cyano-N^1-methylaceta-midine. The technical grade is a white powder soluble in acetone, methanol, dichlorome-thane and acetonitrile. Its acute oral LD_{50} for rat is 417 mg/kg (male), 314 mg/kg (female). It is effective against sucking pests of crops like cotton at 15-20 g a.i./ha. Formulations are 20 SP and 3 EC.

Alanycarb

It is a carbamate insecticide chemically known as Ethyl (*Z*)-*N*-benzyl-*N*-{[methyl(1-methylthioethylideneamino-oxycarbonyl)amino]thio}-*β*-alaninate. Pure product is a colourless crystalline powder. It is suitable for foliar spray, soil treatment or seed treatment. Its acute oral LD_{50} for rat is 440 mg/kg; dermal for rabbit >2000 mg/kg. It is found effective against cotton bollworms at 500 g a.i./ha.

Amitraz

It is N'-(2,4-dimethylphenyl)-N-[[(2,4-dimethylphenyl)imino]methyl]-N-methylmethanimidamide; N-methylbis(2,4-xylyliminomethyl)amine. It belongs to the class Triazapentadiene. It is a white crystalline solid soluble in common organic solvents. Its acute oral LD_{50} for rat is 650 mg/kg; dermal >1600 mg/kg. It is an acaricide and insecticide. It controls psylla, whiteflies and tetranychid and eriophyid mites. Its formulations are EC and WP.

Bifenazate

Its chemical name is Hydrazine carboxylic acid, 2-(4-methoxy-[1'1-biphenyl] –3-yl)-1 methylethyl ester. It belongs to the class carbazate. It is an acaricide for ornamental plants in greenhouse, shadehouse, nursery and field. It is effective against a variety of species of mites and all life stages of *Tetranychus* spider mites. As it is safer to predacious mites and beneficial insects it is ideally suited for Integrated Pest Management and resistance management. It has rapid knock-down and long residual action. It is a product of Uniroyal Chemical Co., the trade name being Floramite.

Cartap

Cartap, $C_7H_{16}ClN_3O_3S_2$, is commonly known as Cartap hydrochloride. The chemical names are: *S,S* - 2-dimethylaminotrimethylene) bis(thiocarbamate) hydrochloride (or) 1,3-bis(carbomylthio)-2-(N,N-dimethylamino) propane hydrochloride. Its insecticidal properties were reported by M. Sakai *et al.* in 1967. Its acute LD_{50}: oral (rat) male 345 mg/kg, female 325 mg/kg; dermal (mice) > 1000 mg/kg. It is systemic with stomach and contact action. It acts on the central nervous system by ganglionic blocking action resulting in paralysis, cessation of feeding and death due to starvation. It is effective against rice stem borer and leaf folder, sugarcane shoot borer, cabbage diamond back moth, etc. at dosages 500-1000 g a.i./ha. Its registered formulations in India are 50 SP and 4 G.

Chlorfenapyr

It is a pyrrole compound. Chemically it is 4-bromo-2-(4-chlorophenyl)-1-ethoxymethyl-5-trifluoromethylpyrrole-3-carbonitrile. Its acute oral LD_{50} for rat is 441mg/kg (male), 1152 mg/kg (female). It is an insecticide and acaricide effective on crops such as roses in polyhouses, cotton, citrus, etc. at 100-300 g a.i./ha. Its formulation is SC. It is safer to *Orius insidiosus* and *Cotesia marginientris.*

Clofentezine

It is 3,6-bis(2-chlorophenyl)-1,2,4,5-tetrazine. It belongs to the class Tetrazine. The technical grade material is a pure odourless, magenta coloured crystalline solid. Its acute oral LD_{50} for rat is >5200 mg/kg; dermal >2000 mg/kg. It is an acaricide with ovicidal action. It is found effective against mites on roses in polyhouses. It is usually formulated as a suspension concentrate.

Dazomet

Chemically it is Tetrahydro-3, 5- dimethyl - l,3,5, thiadiazine - 2 - thione. It is a broad spectrum and soil sterilant introduced by BASF under the trade name Basamid granular containing dazomet 98%. The technical grade is a crystalline solid, white-slightly grey in colour. Its spectrum of activity is related to control of soil-borne diseases (fungi and bacteria), nematodes, soil insects, weeds and rhizomes and tubers of perennial weeds. It is non-toxic to bees. It decomposes in water to yield fumigant vapour. Its oral LD_{50} is 640 mg/kg, dermal > 2000 mg/kg. It is recommended for effective management of root-knot nematodes and weeds in FCV tobacco nurseries in Karnataka as a suitable alternative to methyl bromide fumigation. Prior to application of granule apply recommended quantity of FYM in the nursery. Water the seed-beds daily for a week to facilitate hatching of root-knot nematode eggs and also to induce germination of weed seeds. Broadcast dazomet granule uniformly @ 30 g/m and incorporate the microgranules into the soil to a depth of 10 cm. Irrigate the beds sufficiently and cover it with polyethylene sheet, sealing it all round. Remove the cover after 15 days and loosen the soil, aerate the beds for three to five days and then take up sowing. This effectively controls root-knot nematodes, fungi, nut grass, etc. and provides healthy transplants.

Dienochlor

It is Bis(pentachloro-2,4-cyclopentadien-1-yl); decachlorobis (2,4-cyclopentadien-1-yl). The technical grade is a tan crystalline solid. Solubility is slight in aliphatic hydrocarbons and acetone; moderately soluble in aromatic hydrocarbons. Its acute oral LD_{50} for rat is 3160 mg/kg; dermal (rabbit) >3160 mg/kg. It is an acaricide for the control of mites on indoor floral plants such as rose. The formulaltion is 50% EC.

Emamectin benzoate

It is a semi-synthetic avermectin derived from fermentation of avermectin B (abamectin); mixture of 4" epimethylamino-4" deoxy-avermectin B1a and B1b benzoate salts. The technical grade is a white to off-white powder. Its LD_{50} for rat- oral 1516 mg/kg, dermal >2000 mg/kg. It is an insecticide for use in cotton. Formulation is EC.

Fenazaquine

It is registered in India as 10% EC and found effective against mites on tea. Also effective against coconut eriophyid mite at 200–250 ml/100 litres water or root feeding at 10 ml/palm.

Fipronil

Fipronil, $C_{12}H_4C_{I2}F_6N_4OS$, is chemically (5-amino-1-(2,6-dichloro-4-(trifluoro-methyl)phenyl)-4-(1,R,S)-(trifluoromethyl)su-1-H-pyrasole-3-carbonitrile. It belongs to the class Fiproles. It is an insecticide and acaricide effective against pests of rice in India. Acute oral LD_{50} for rat 100 mg/kg; dermal for rat > 2000 mg/kg. Its registered formulations in India are 0.3% Gr. and 5% SC. It is effective against pests of rice at 50-75 g a.i./ha. Fipronil 0.05% gel formulation for control of household pests has been developed.

Imidacloprid

Imidacloprid, $C_9H_{10}CIN_5O_2$, is chemically1-(6-chloro-3-pyridylmethyl)-*N* nitroimidazolidin - 2 - ylideneamine. It belongs to the class Chloronicotinyl. Acute oral LD_{50} for rat 450 mg/kg; dermal for rat > 5000 mg/kg. It is a systemic insecticide with stomach and contact action. Controls sucking insects, soil insects, rice water weevil etc. It is used as a seed dressing or foliar/soil treatment for control of pests of cotton, rice, etc. The 75WS formulation is treated with cotton seed at 10 g/kg seed which provides protection against whitefly and leafhopper up to 40 days after sowing.

Indoxacarb

It belongs to the new class of chemistry – Oxadiazine. Chemically it is (S)-methyl 7-chloro-2,5-dihydro-2[[(methoxy-carbonyl) [4-trifluoromethoxy)phenyl]amino]carbonyl]-indeno[1,2-e] [1,3,4]oxa-diazine-4a(3*H*)-carboxylate. Molecular wt. 527.84; Empirical formula $C_{22}H_{17}ClF_3N_3O_7$. Technical is white powder. Its acute oral LD_{50} for rat is 3619 mg/kg (male), 751 mg/kg (female); dermal (rat) >5000 mg/kg. It is effective against diamondback moth on cabbage and *Helicoverpa armigera* on cotton at 75 g a.i./ha. On cotton it is recommended to be applied at square and flower formation stage, boll formation stage and boll maturity stage. It is useful in Insecticide Resistance Management (IRM) programmes. Formulation 14.5% SC.

Pymetrozine

It belongs to the class Pyridine azomethines. Chemically it is 1,2,4-triazin-3(2H)one,4,5-dihydro-6-methyl-4-[3-pyridinylm-ethylene)amino]. Its acute LD_{50} for rat – oral > 5000 mg/kg, dermal >2000 mg/kg. It is effective against scales and aphids at 100-300 g a.i./ha.

Pyridaben

It belongs to the class Pyridazinine and chemically it is 2-tert-butyl-5-(4-tert-butylbenzylthio)-4-chloropyridazin. Its acute oral LD_{50} for rat is 82-1350 mg/kg; dermal >2000 mg/kg. It is a white crystalline material soluble in methylene chloride; relatively soluble in acetonitrile and ethanol. It is an acaricide and insecticide. It controls mites on ornamentals and field crops. It is also effective against psyllids, leaf hoppers and white/flies. Formulations EC, SC and WDP.

Spinosad

This is an insecticide of natural origin, containing a mixture of two components derived from fermentation technology produced by *Saccharopolyspora spinosa*, a species of actinomycete. It comprises of spinosyn A + spinosyn D. Its acute oral LD_{50} for rat is >5000 mg/kg. It is formulated as 45 SC and is active against *Helicoverpa armigera*, leaf hopper, aphid and white/fly on cotton at 75–100 g a.i./ha. For diamond back moth on cabbage 2.5% SC has been found effective at 15.0–17.5 g a.i./ha.

Thiomethoxam

It belongs to Nionicotinoid group. Seed treatment with 70 WS at 4 g/kg seed or foliar spray of 25 WG at 25-50 g a.i./ha is effective against sucking pests of cotton and pest complex of rice.

5. Fumigants

A fumigant is a gaseous poison used to kill insects, nematodes and rats, and its application is limited to live plants or products in tight enclosures or to soil. The gas enters the insectan body through spiracles in the case of larvae, pupae and adults, and the eggs through the chorion and brings about death. A fumigant that vaporises readily at room temperature is the most useful. An essential requirement of a soil fumigant is that the vapour should emerge slowly. An ideal fumigant is determined by its relative effectiveness, cost, penetrating power, safety to human beings, living animals, plants and germinating seeds, reactivity with household furnishings, flammability etc. Fumigants are employed to control diverse varieties of stored product pests, pests on household articles, etc. Soil fumigation is done to eradicate soil dwelling insects and nematodes. Live plants are fumigated for controlling subterranean pests. As a quarantine measure imported plants are also fumigated.

In any fumigation operation the first principle to be observed is to safeguard human lives and only trained personnel with necessary protective appliances should be entrusted with the work. The enclosure to be fumigated must be as nearly air tight as possible and it is better to avoid windy or cold weather. There should be provision for ventilation after fumigation. If living plants are fumigated, accurate dosage must be used in addition to scrupulously following the proper time for exposure and ventilation, and the temperature should be at an optimum between 14-27°C. It is desirable to have the treatment done at night or in darkness. If no live plants are involved, the fumigant is used slightly in excess and the materials are exposed as long as convenient. The temperature is to be between 21 and 38°C. Food substances containing moisture may get poisoned after fumigation.

The dosage for fumigation is expressed in terms of lb/1000 cu. ft. or oz/1000 cu. ft. or g/m^3 and an effective fumigant should bring about 99 % destruction of the insect population which is referred to as the critical (Ct) value. The Ct value is the product of the concentration of the gas per unit volume multiplied by the duration of the exposure. For a successful programme, the following information will be necessary:

(i) The volume of enclosed space; and

(ii) The rate of release of fumigant vapour.

If the exposure period is shorter the concentration of the gas needed will be more. The sorption of the gas by the material fumigated affects the dosage and the critical value of the fumigant. And further, the rate of sorption is dependant on the moisture content of the material. The dosage recommended is intended for a standard period of exposure to achieve useful results, and in live plants it is limited to the amount that could be tolerated without any apparent phytotoxic effects. Tent fumigation is adopted for fumigating trees, tents being relatively airtight into which a hose introduces the gas. Vacuum fumigation is done using gas in a partial vacuum to enhance penetration and to save time.

The following are some fumigants which find use in control of storage pests.

5.1 Hydrogen Cyanide or Hydrocyanic Acid: HCN

This is the most extensively used fumigant, originally employed for the control of the cottony cushion scale in the USA. It is a volatile, colourless liquid with a bitter almond odour and a specific gravity of 0.699 at 20°C. The gas has specific gravity of 0.943 and is highly inflammable and explodes in mixtures above 5.6 % or above 64 g/m^3. Under normal atmospheric pressure the gas is not able to penetrate and a partial vacuum fumigation is employed. Metals like gold, brass, nickel, etc. are tarnished by HCN, which could be removed by promptly rubbing with polishing cloth or prevented by prior application of grease. HCN is liberated when sodium or potassium cyanide is treated with sulphuric acid or on exposure of calcium cyanide to moist atmosphere. Cyanogas contains 40 to 50 per cent CaCN and the gas is liberated slowly. It is used in fumigation of burrows of rats. The plants/trees to be fumigated should not be watered for some hours previous to fumigation. The gas is not compatible with Bordeaux mixture and hence should not be applied on plants before or after fumigation. HCN is one of the most deadly gases and at higher dosages or if exposed too long it may kill plants. The gas becomes toxic to insects and warm blooded animals as it combines with iron atoms of cytochrome oxidase. Only experienced persons should be allowed to handle fumigation. Gas masks should be used. For general fumigation the dosage is 10-16 g sodium cyanide (98 % pure), 20-30 ml sulphuric acid and 40-60 ml water per m^3. For fumigating live plants the dosage is 12-25 g sodium cyanide, 20-40 ml sulphuric acid and 40-80 ml water for 100 m^3.

Carbon Bisulphide

Also known as carbon disulphide. It was first employed in France to control pests of stored grains. It is a colourless liquid with a disagreeable odour due to traces of hydrogen sulphide. It has a specific gravity of 1.263 at 20°C and vapour pressure of 360 mm Hg at 25°C. It is slightly soluble in water but soluble in organic solvents, highly inflammable and explosive in mixtures above 1 % in air. It is used for the control of stored product pests in godowns, and pests of clothes, dress and draperies. It has also been used to control wood borers, bots and intestinal larvae, which are given gelatine coated capsules. Emulsions are used in controlling soil insects and nematodes. Fumigation is done at temperatures ranging from 75 to 90°F. The dosage is 10 lb of carbon bisulphide per 1000 cu. ft of space or 2 to 3 gallons per 1000 bushels of grain for 36 to 72 hr. It does not affect the milling qualities of the grain, germination of seeds and does not leave residues on seeds. The gas possesses good penetrating power. When used as a soil fumigant it is known to stimulate growth of many kinds of crops. Commercial mixtures of 20 % CS_2, 80 % CCl_2, and a trace of SO_2 have a greatly reduced fire hazard and the dosage is 15 to 20 lb/1000 cu. ft. of space or 3 to 5 gallons/1000 bushels of grain. The fumigant is highly phytotoxic.

Methyl Bromide or Bromomethane

It is one of the most widely used fumigants. It has a low boiling point and at ordinary temperatures it is a colourless and odourless gas. Its vapour pressure is 1580 mm Hg at 25°C and the gas is not inflammable. The specific gravity is high, 1.732 at 0°C and this is the commonly used fumigant. It requires a longer period of exposure as it kills the insects slowly. A dosage of 24–32 g/m^3 with an exposure period of 48 hours is advocated for stored grain pests. For termites, powder post beetles, etc. tents with a dosage of 32–64 g/m^3 is employed. In plant quarantine centres fumigating live plants, nurseries, etc. fumigation is done with 16-32 g/m^3. However, some plants are adversely affected by methyl bromide. For soil fumigation 4.7 ml/sq. ft. is used in combating insects, weeds and nematodes. The fumigant is a dangerous cumulative poison to warm blooded animals; the nervous system is affected and lethal results are produced. A gas mask with cannister should be worn always by the technician employing the fumigant. Picric acid (2 %) is added to cylinders of methyl bromide, which causes irritation of eyes in case the gas persists in the area of fumigation. A halide detector lamp shows a blue flame if the gas is present.

Chloropicrin or Trichloronitromethane

It is a tear gas of limited use in controlling insects. Its specific gravity is 1.651 at 20°C and vapour pressure 24 mm Hg at 25°C. It is a colourless to yellowish liquid stable at room temperature. It is slightly soluble in water and soluble in organic solvents. It possesses good penetrating ability, non-inflammable, corrodes metals slightly but does not bleach or tarnish. In the control of household and stored product pests, the dosage used is 16-48 g/m^3. Chloropicrin should not be used on growing plants or germinating seeds. It is useful as a soil fumigant against some soil forms and nematodes. The low volatility of the compound makes it difficult to remove the gas and in routine fumigations of inhabited areas this is not employed.

Carbon Tetrachloride

Carbon tetrachloride is a colourless liquid with specific gravity 1.595 at 20°C and vapour pressure of 114.5 mm of Hg at 20°C. It is almost insoluble in water but soluble in organic solvents. The gas has a specific gravity of 5.31, is not inflammable or explosive and possesses pungent chloroform-like odour. It is comparatively less toxic to insects and slow acting and is so not very much used. When used with carbon bisulphide or ethylene dibromide it reduces fire hazard. It increases the volatility and distribution of fumigants like methyl bromide, ethylene dichloride and chloropicrin.

Ethylene Dichloride or 1,2 Dichlorethane

This is a colourless liquid with specific gravity of 1.257 at 20°C, vapour pressure of 78 mm Hg at 25°C. The gas is inflammable between 6 and 16 % in air and has a specific gravity of 3.4. It is slow acting and destruction of insect takes place from one to three days after exposure. Most germinating seeds are not affected, but is phytotoxic. Generally, it is used with carbon tetrachloride as a fumigant.

EDCT or Ethylene Dichloride-Carbon Tetrachloride Mixture

It is a general fumigant mixture consisting of three of ethylene dichloride and one of carbon tetrachloride by volume. Such a mixture, either as gas or as liquid is free from fire hazard. It could be transported or stored in cans. This, when poured or sprayed on to the material, vapourises and fumigates. The temperature is usually kept at 24°C. The dosage is 160–300 g/m^3 in airtight stores for 24 hours. In fumigating chests, wardrobes, etc. double the above dosage is recommended.

Ethylene Dibromide or 1.2-Dibromomethane

Ethylene dibromide is a colourless liquid with specific gravity of 2.172 at 20°C and vapour pressure of 11 mm Hg at 25°C. The gas has a specific gravity of 6.5 and is non-inflammable. It is used at 8 g/m^3 for destroying fruit fly larvae in fresh fruits and vegetables and this does not affect the plant materials. As a soil fumigant it is used for the control of wireworms, whitegrubs, etc. at a dosage of 18 to 72 lb/acre in 20 gallons petroleum naphtha injected into the soil. As it is toxic to many plants the soil should be aerated thoroughly. It is formulated as liquid, granule and even as capsule. The liquid is injected into soil at 15 to

20 gallons/hectare and the 35 per cent granular material is dibbled in the soil at a depth of 15 to 20 cm at a spacing of 30 x 30 cm at 300 lb/acre for the control of nematodes.

DD is a mixture of two-thirds 1,3-dichloropropene and one-third of l,2-dichloropropane or propylene dichloride. It is injected into the soil for the control of wire-worms, centipedes and nematodes. The liquid is injected into the soil at a depth of 15 to 20 cm at a spacing of 30 × 30 cm as pre-plant treatment at least two weeks before planting because of its highly phytotoxic nature. It is not being used in India.

Phosphine

Phosphine or hydrogen phosphide is widely used to fumigate grain, flour and cereals in godowns. The commercial products available as tablets or pellets or plates are aluminium phosphide or magnesium phosphide, which on contact with moist air release phosphine. The gas is highly toxic to all stages of insects.

Paradichlorobenzene

Paradichlorobenzene is a white, crystalline material vapourising slowly (vapour pressure 1 mm Hg at 25° C) into non-inflammable gas with ether-like odour. Its specific gravity is 5.1. It is only slightly soluble in water. It is used as a soil fumigant for controlling apple woolly aphis. Carpet beetles and clothes moths in homes and museum pests like dermestids are controlled by the gas. This was also used against red palm weevils. A dosage of 12 g/m^3 is suggested.

Naphthalene

Naphthalene is a white crystalline material with specific gravity of 1.517 at 15°C. It vapourises slowly with vapour pressure 0.08 mm Hg at 25°C. It is inflammable when mixed with air. It is slightly soluble in water, but readily dissolves in organic solvents. It is used against clothes moths, carpet beetles, etc. at 1 g/m^3. It is available as moth balls or moth flakes.

6. SYSTEMIC INSECTICIDES

Systemic insecticides find use in the control of insects infesting animals and plants.

6.1 Systemic Insecticides for Animals

In animals systemic insecticides have been used for the control of internal parasites such as screw-worm larvae, cattle grubs and helminths and external parasites such as ticks, mites, lice, stableflies, etc. The insecticide used should not be harmful to the host animal but should be toxic to the pest species only. These compounds are either applied topically or administered orally to the animals. The toxicant is found to move in the tissues of the animal in quantities sufficient to bring about kill of the parasites. The slow destruction of the toxicant in the tissues is achieved by enzymatic action and an animal is recommended for slaughtering or for milching after a safe period of about 60 days from the time of application or administration of the toxicant. Two systemic insecticides used widely for the control of animal parasites have been crufomate (Ruelene) and fenchlorfos (Ronnel).

6.2 Systemic Insecticides for Plants

A systemic insecticide is one in which the toxicant penetrates into all plant tissues and gets transported in insecticidal quantities from the point of application in apical direction and possibly with a weak downward flow restricted to single leaves but not in the whole plant, and displays endo-therapeutic effects over a sufficiently long period. Some chemicals like nicotine, HCH, parathion, etc. possessing penetrating ability exhibit translaminar action and are not generally translocated and stored as in true systemics. If some translocation is observed it would be in very small quantities to those applied.

The chief requirements for an effective and safe systemic compound are:

(i) High intrinsic pesticidal activity,

(ii) Adequate liposolubility of the toxicant for absorption by the plant system,

(iii) Sufficient water-solubility to enable translocation,

(iv) Stability of the compounds or its metabolites for sufficiently long period to exercise residual effect, and

(v) Susceptibility to decomposition into non-toxic products in the plant system.

The main advantages of systemic insecticides are:

(i) The toxicant is not subjected to weathering as it penetrates into the plant system and remains in it sufficiently long to exercise residual effect;

(ii) As the toxicant is translocated in apical direction, fresh plant growth formed subsequent to application needs no treatment for a reasonable period; and

(iii) Due to selective action exhibited by systemic toxicants, beneficial insects like parasitoids and predators and pollinating insects like bees are not destroyed.

The systemic insecticides are applied variously such as treatment of seeds before planting, application of granular formulation of the toxicant in seed furrows before sowing, implantation of encapsulated material about the roots or into the stem, drenching the soil, broadcasting the material in standing water in rice fields, direct application or injection of concentrates to the stem or trunk, and foliage spray application.

Absorption: Though the entire plant surface and seeds can absorb the toxicant, the most important organs of uptake are the roots and leaves. The type of formulation, dosage, characteristic of plant species, part treated, edaphic and other ecological factors govern the degree of absorption of the toxicant. The largest quantities of absorption of the toxicant by roots takes place from aqueous solutions and the uptake decreases in proportion to the increase in the content of absorptive constituents, especially humus as in demeton, disulfoton, phorate, etc. In the control of aphid on potato, granular dimethoate and menazon are reported to be more effective in wet than in dry soils, whereas disulfoton and phorate are equally effective in both. However, even with the former two the effects of moisture is small and is probably the result of several different interacting factors. Selective action in absorption of the toxicants through roots is exhibited by plant species. The uptake is greater with increased physiological activity of the plant under relatively high temperature with adequate moisture.

Leaf absorption takes place in several ways, the young leaves being more absorptive than old leaves and generally the absorption is greater on the undersurface of leaves than on the upper surface. For highly liposoluble materials the most important route of entry is the cuticle rather than the stomata. The surface of leaf veins, being composed of thin-walled cells, favours easy penetration. The retention of spray droplets as also the range of time taken for absorption are important. Phosphamidon and monocrotophos are absorbed in a few hours as against a few days in the case of thiono isomer of demeton and Schradan. Temperature and light are important factors in controlling absorption through leaves and the relative response of the plants varies with plant species.

Bark of stem and branches of woody plants like coffee and citrus absorb systemic insecticides like Schradan, demeton, and dimefox, and it appears that in woody plants the absorption through trunk is more efficient than through roots. Monocrotophos, dicrotophos and phosphamidon are also similarly absorbed in herbaceous plants.

Soaking of seeds in the chemical or coating the seeds with it or application of the chemical at sowing are some methods by which absorption of the active ingredient by seeds is achieved. The absorption is rapid when seeds are soaked in the chemical. Absorption by seeds is dependent on the method, type of seed and the lipoid and water-solubility of the toxicant. In the case of seed soaking or coating, while absorption through cotyledons takes place, part of the toxicant may diffuse out of the seed into the soil where it can be absorbed by the developing roots.

Translocation: In this process the toxicant absorbed is transported along the transpiration stream towards plant parts of intense metabolic activity resulting in varying levels of temporary accumulation. The parent compound or its metabolites should be more water-soluble for efficient translocation. Demeton thiol isomer having a solubility range of 2000 to 3900 ppm is rapidly translocated than thiono isomer having a solubility range from 60 to 1250 ppm. Better translocation of disulfoton and phorate is achieved on oxidation to more soluble sulfoxide and sulfone derivatives. The toxicant absorbed by roots is transported upward and gets distributed to shoots chiefly with the transpiration stream, the xylem. There may also be some of localised lateral diffusion into phloem. The speed of translocation increases with increase in transpiration, which in turn is influenced by high temperature coupled with adequate humidity.

In foliar application, the movement of the systemic insecticide in a treated leaf occurs from the base to the apex and a very slow migration in the opposite direction may occur through diffusion from cell to cell to the leaf base. Recent evidences suggest that downward flow of systemic phosphates in phloem from treated to untreated leaves occurs in very low amounts of insignificant therapeutic value or does not take place at all. Therefore, an even distribution of a systemic insecticide over the whole plant cannot occur in case of partial treatment of foliage.

In bark or stem implantation treatment the active ingredient absorbed is translocated in the upward direction. Downward transport of metabolites through phloem is negligible and is mainly a resultant of radial transfer from xylem.

Storage and Metabolism: The organophosphorus (OP) systemic compounds translocated in appreciable quantities are stored in distinctive sites in plants and are subjected to oxidative and hydrolytic metabolism and dehydration. Consequently, activation and detoxification will result. Similar reactions occur in the bodies of the insects and mammals.

The organophosphorous systemic compounds, based on their behaviour in the plant system, are classified as: Endolytic systemic compounds, and endometatoxic systemic compounds. In the former, 98 % of the parent compound exists in its original form when ingested by the pest species, until it is decomposed by the plant and the toxic action results from enzymatic metabolism within the pest species, for example is Schradan. In the latter, the toxicants are transformed in the plant either partially or wholly into other toxic compounds which are also toxic when ingested by pest species before they are decomposed by the plant, e.g. some phosphates, the thiono and thiol isomers of demeton, methyl demeton (phosphorothionate and phosphorothiolate), phorate, dimethoate, disulfoton (phosphorothiolothionate). The rate of metabolism of endometatoxic compounds within plants is accelerated by higher temperatures due to the acceleration in the physiological activity of the plant. The ultimate systemic effect in most cases is the result of a combination of oxidative and hydrolytic process comprising of the evolution of relatively unstable products which are generally more polar and thus more water-soluble than the parent compound to promote easy translocation.

The primary cause of organophosphorus poisoning in insects is attributed to inhibition of the cholinesterase enzyme system. Organophosphates also block other enzymes, viz. aliesterase in insects, which are important in detoxification process.

Some organophosphorus systemic compounds such as Schradan and phosphamidon are more water-soluble and exhibit very little affinity for the body lipids, which account for their relatively low dermal toxicity.

Among inorganic compounds, sodium selenate is said to be systemic. After World War II organic systemic insecticides have been synthesised in large numbers. Systemic organophosphates belong to phosphates, phosphorothionates, phosphorothiolates, phosphorothiolothionates, etc. A few systemic carbamates include carbofuran and aldicarb.

Systemic insecticides are used for the control of sucking insect pests, midges, leafminers, borers, mites, etc.

7. COMPATIBILITY OF SPRAY CHEMICALS

When two chemicals are brought together in a single spray mixture, due to reaction, a compound differing from either parent may be formed. On application, a knowledge of the effects of such compounds on the plants is essential to avoid improper use. The incompatibility in such cases may be:

(1) Chemical incompatibility : Different compounds are formed due to reaction of various chemicals as in synthetic organic compounds with an alkaline material.

(2) Phytotoxic incompatibility: The component parts though by themselves are not injurious to the plants and do not show any chemical reaction when mixed, the mixture causes injury to plants.

(3) Physical incompatibility: In this case the chemicals used to change their physical form to one that is unstable and hazardous for application.

8. FACTORS INFLUENCING EFFECTIVENESS OF INSECTICIDES

The various factors that influence effectiveness of pesticides are:

1. The mode of entry of the chemical into the body of the insect: Adding an oil to a spray mixture makes it lipophilic and thus it is able to penetrate through the cuticle and increase its toxicity. Stomach poisons are absorbed in the midgut.

The spray enters or penetrates the tracheal system easily if its surface tension is lowered by addition of a material.

2. The developmental stages of an insect larvae and nymphs are often more susceptible than the other stages.
3. Effectiveness of insecticides is affected by environmental conditions. Generally quick acting poisons are more effective at high temperatures but get detoxified inside the body of the insect early. Slow-acting poisons are effective at lower temperatures. Fine mists produced in concentrate spraying may dry off under conditions of low relative humidities. Water soluble sprays may be washed off by rains. Sunlight is responsible for the break-down of the residues of certain insecticides. Air current affects dusting and spraying operations resulting in uneven coverage and especially so when applied with aircraft.
4. The condition of the plant is another important factor. In case of plants having waxy leaves the spray solution may run off and this can be corrected by additions of a wetting agent. When there is heavy or thick foliage the coverage of the insecticide may not be even.

◆ Chapter 90

Botanical Insecticides

In recent years misuse or overuse or indiscriminate use of pesticides in crop protection has caused serious environmental problems, pest resurgence, pest resistance to pesticide, toxicity to non-target beneficial species and those handling them. It has, therefore, become necessary to search for alternative means, which can minimise the use of synthetic chemicals. In this context use of botanical pesticide/ natural plant products is emerging as a major thrust area in integrated pest management and research has been intensified. Many plant products have been reported to possess insecticidal activity, repellency to pests, antifeedancy, insect growth regulation, etc. It has been reported that around 866 plant species have activity against insect species. The botanical pesticides have the following advantages over synthetic pesticides.

a) Possess low mammalian toxicity and thus constitute least/ no health hazards and environmental pollution.

b) No risk of developing resistance if used in natural forms.

c) Less hazardous to non-target organisms.

d) Not known to cause resurgence of pest species.

e) Non-phytotoxic to crop plant.

Following are some important plant species, which have been explored or can be explored for their potential in crop protection.

1. *Acorus calamus* Linn. (Araceae) (Sweet flag)

In India this plant is grown primaraily in Jammu & Kashmir, Manipur, Mysore and Northern Himalayas. It is reported to have insecticidal, insect repellent, antifeedant, attractant and chemosterilant properties against insects in storage and field. Rhizome/root powder and its extracts are effective against insect pests such as *Rhyzopertha dominica, Sitophilus oryzae, Tribolium castaneum, Latheticus oryzae,* and *Sitotroga cerealella* of paddy and *Callosobruchus chinensis* of pulses in storage. Sweet flag oil is also reported to be toxic to these pests. The oil has shown chemosterilant effect in *Trogoderma granarium* and *C. chinensis.* Ethyl ether extract of the rhizome exhibited attraction of both male and female of Mediterranean fruit fly *Ceratitis capitata* and the Oriental fruit fly *Bactrocera dorsalis.* Four components of the oil are methyl eugenol, β-asarone, acoragermacrone and agarylaldehyde, which are responsible for the attraction of fruit flies.

2. *Allium sativum* Linn. (Amaryllidaceae) (Garlic)

This plant is commonly grown in northern and central states of India. Bulb extract and garlic oil possess insecticidal and insect repellent properties against insects infesting grains in storage and crops in the field. The active component from garlic extract was identified in 1971 as 'allitin', a mixture of diallyl di- and trisulphides, which inhibits cholinesterase activity in insects and effective against insects in stored paddy. In 1980 the active compound 1-3, diphenyl thiourea was extracted which was effective against the rice weevil *S. oryzae.* Its unpleasant odour and low persistence are undesirable traits.

3. *Annona reticulata* Linn. (Annonaceae) (Bullocks heart or Custard apple)

It is a perennial tree found in West Bengal, Assam, Khasi Hills and South India and has edible fruit. Its bark, leaf, fruit and seed exhibit insecticidal, antifeedant and repellent activities against a number of agricultural insect pests infesting grains in storage as well as crops in the fields. Seed extract contains the insecticidal components such as glycerides of hydroxylated unsaturated acids. In 1971 'anonaine', a toxic alkaloid from *Annona* spp. was reported to have insecticidal activity. Anonaine occurs along with other relative alkaloids viz., roemerine, nuciferine, recticuline and 6-methoxy, 7-hydroxy aporphine, which are also toxic to insects.

4. *Annona squamosa* Linn. (Custard apple, Sweet soap, Supper apple)

It is a perennial shrub or small tree found throughout India. Its roots, leaf, fruit and seed extracts in water, ether and alcohol and their powders have shown insecticidal, antifeedant and repellent activities against insect pests in storage and in the field. Its seed oil when sprayed on rice crop was reported to effectively reduce the survival of *Nephotettix virescens* and transmission to rice tungro virus, and survival of the rice leaf folder *Cnaphalocrocis medinalis*. Spray of leaf extract reduced the survival of the whitefly *Bemisia tabaci* and also transmission of yellow mosaic virus (YMV) in mung bean crop. Its insecticidal component is the alkaloid, anonaine.

5. *Azadirachta indica* A. Juss. (Meliacea) (Neem or Margosa tree)

This is a perennial tree distributed in tropical, subtropical, semi-arid and arid zones. It is found throughout India and a highly explored tree species. It possesses medicinal, insecticidal, insect repellent, antifeedant, growth regulant, nematicidal and antifungal properties. Its insecticidal properties against a wide range of pests in storage as well as in the field is well known. Dried powder of neem leaves admixed with sorghum or wheat grains afforded protection against stored grain pests. Leaf extract of neem also showed insecticidal activity against important field pests such as *Plutella xylostella, Hypera postica, Aproaerema modicella, Spodoptera litura,* etc. The desert locust, *Schistocerca gregaria,* avoids feeding on neem leaves. Neem leaves proved to be an attractant to the adults of the beetles *Holotrichia serrata, H. consanguinea* and *H. insularis,* whose grubs damage seriously sugarcane roots. This has facilitated collection and destruction of the adults during dusk. Neem leaf bitters (NLB) have been found to reduce the oviposition and development of the green leaf hopper *Nephotettix virescens* and the brown plant hopper *Nilaparvata lugens* on rice.

Neem seed/kernel extract also showed insecticidal activity against storage pests. It also showed antifeedant activity against the desert locusts *Locusta migratoria* and *Schistocerca gregaria, Amsacta moorei, Spodoptera litura, Epilachna varivestis,* etc. Neem oil also proved to be useful against a large number of insect pests in storage (1 to 2% neem oil w/w) and in the field (0.2 to 0.4%, 1 to 2%, or 5% or 10% neem oil). Neem kernel powder as well as cake have also shown insecticidal activity.

From the neem seed extract and oil a number of components have been identified of which azadirachtins, deacetyl-salannin, salannin, nimbin, epinimbin and meliantriol possess biological activities such as insect repellent, antifeedant, growth inhibitor/regulator and insecticidal. Azadirachtins, a group of C_{26} terpenoids, are structurally similar to the insect ecdysones. Azadirachtin was first reported in 1986 from neem seeds, which exhibited feeding inhibitory effect in the desert locust *S. gregaria.*

Azadirachtin

Extracted from the kernels of the neem tree *Azadirachta indica.* Chemical name is dimethyl [2aR-[2aα, 3β, 4β (1aR*, 2S*, 3aS*, 6aS*,7S*,7aS*), 4aβ,5α,7aS*,=8β(E),10β,10aα,10bβ)]-10-(acetyloxy) octahydro- 3,5- dihydroxy-4- methyl-8-[(2-methyl-1-=oxo-2-butenyl)oxy]-4-(3a,6a,7,7a-tetrahydro-6a-hydroxy-7a-methyl-2,7-methanofuro[2,3-=b] oxireno[e]oxepin-1a(2H)-yl)-1H,7H-naphtho [1,8-bc: 4,4 a-c'] difuran-5,10a(8H)-= dicarboxylate. Molr. wt. 720.7; Molr. Formula $C_{35}H_{44}O_{16}$. It is an yellow-green powder with a strong garlic /sulfur odour. Acute oral LD_{50} for rat >5000 mg/kg, acute dermal for rabbit >2000 mg/kg. It disrupts insect moulting by antagonizing the insect hormone ecdysone and is also an antifeedant to some insects.

Formulations of neem products: Several agrochemical companies have either introduced or testing different formulations of neem based products and some have been registered in the country for use.

Replin is a mixture of oils of neem, kharanja, castor, mahuwa and gingelly, and azadirachtin constitutes 300 ppm in it. It is effective against field crop pests at 1-2%. Margosan O constitutes neem oil fraction and effective as 2% solution. Neemark constitutes neem seed oil with azadirachtin in the crude form. Welgro is a product of neem kernel powder. Neemrich is a dichloroethane extract effective as 0.1% spray against *Spodoptera litura.* Achook is a water soluble powder (WSP) that contains 0.03% azadirachtin, azadiradion, nimbocinol, and ebinimbocinol as active principles. It has been found effective against *Helicoverpa armigera* and *Earias vittella* on cotton.

6. Pyrethrins

Pyrethrum was used as an insecticide at about 1800 in the Transcaucasus region of Asia. The six insecticidal constituents present in extracts of the flowers of the plant *Pyrethrum cinerariaefolium (=Chrysanthemum cinerariaefolium)* (Asteraceae) are collectively known as pyrethrins and comprise esters of the natural stereoisomers of chrysanthemic acid viz., pyrethrin I, cinerin I and jasmolin I, and the corresponding esters of pyrethric acid viz., pyrethrin II, cinerin II and jasmolin II. Most commercial extracts contain 20-25% pyrethrins. Generally the ratio of pyrethrin: cinerin: jasmolin is reported to be 71:21:7. Pyrethrins are extracted commercially from crops grown in Kenya, Tasmania and Tansania. The extract is refined using methanol or supercritical carbon di oxide and the crude extract is dark brown. Pyrethrum flowers contain 0.924 to 1.178% pyrethrins and 90% of the pyrethrins occur in the achenes of the flower head.

It is a contact insecticide and causes paralysis initially and death follows. Pyrethrum is formulated as dusts, emulsions, solutions and aerosols. The pyrethrin content ranges from 0.05 to 0.10%. It is useful against a wide range of insect and mite pests of public health, stored grains, animal houses and on pets and farm animals. Normally it is combined with the synergist piperonyl butoxide, which inhibits detoxification. Due to its lack of persistence and instability in the presence of light it does not find acceptance in agricultural pest control. Its acute oral LD_{50} for rat: male 2370 mg/kg, female 1030 mg/kg; dermal for rat >1500 mg/kg.

Pyrethrum 2% dust and Pyrethrum 1% EC have been registered in India for use against insect pests of vegetables. For household pest control the formulations used are: pyrethrum 0.05% + synergist 0.05% HH, pyrethrum 0.2% RTU, pyrethrum 0.05% + lindane 0.05% RTU, pyrethrum 0.02% + lindane 0.02% + synergist 0.5% RTU, pyrethrum 0.02% + malathion 0.05% + synergist 0.5% RTU, pyrethrum 0.05% + lindane 0.05% RTU, pyrethrum 0.05% + malathion 1% aerosol, pyrethrum 1% aerosol, pyrethrum 0.2%HH, and for public health pyrethrum 2% EC and pyrethrum larvicidal oil 0.2% EC.

A number of synthetic pyrethroids have been synthesized by alteration in their structures and configurations, which have photo stability and insecticidal activity. Allethrin was the first synthetic pyrethroid developed.

7. *Derris elliptica (Wall.) Benth.* (Fabaceae) (Derris or Tuba-root)

This is a perennial shrub grown in tropical and subtropical regions. Root of the plant is an effective poison for fish and insects. As early as 1848 it was known as an insecticide. The root contains the derris resin, which constitutes rotenone (25%) and related components called rotenoids. It is a stomach poison to insects. Poisoned insects exhibit a steady decline in oxygen consumption followed by paralysis and death. It also has acaricidal activity. It is chemically (2*R*,6a,*S*,12a*S*)-1,2,6,6a,12,12a-hexahydro-2-isopropenyl-8,9-=dimethoxy chromeno[3,4-b]furo[2,3-h] chromen-6-one. Molecular. wt. 394.4; Molecular. formula $C_{23}H_{22}O_6$. Acute oral LD_{50} for rat: 132-1500 mg/kg.

Rotenoids or rotenone are known to be present in species of leguminous plants and the principal economic plants are *D. elliptica* and *D. malaccensis* (contain 5 to 9 % rotenone) in the Far-East and *Lonchocarpus utilis* and *L. uruca* (contain 8 to 11 % rotenone) in South America. Rotenone is the chief among the toxic constituents obtained from the roots of these plants, the other naturally occurring rotenoids being elliptone, sumatrol, malaccol, toxicarol, deguelin, tephrosin, etc. The roots are dried and powdered and mixed with three to seven parts of a diluent such as talc, clay, gypsum, etc. to be used as a dust containing 0.05 to 0.10 per cent rotenone. Dusts are reported to be useful in the control of external parasites of animals, such as fleas and lice and also for the control of ox warbles. The commercially available crystalline rotenone is used for moth proofing and does not stain the material.

8. *Lobelia excelsa* (Companulaceae)

This plant is found on the Western Ghats in South India at an elevation of 2000 m. The leaves are cured in shade and chopped, and 1 kg of the leaves are soaked in water for about a day. The infusion is filtered and the filtrate made up to 20 litres and 60 g of soap is added. It was reported to be effective against aphids on snakegourd and cowpea, tingids on brinjal and mites on castor and lady's finger.

9. *Madhuca indica* J. F. Gmel. (=*Bassia latifolia)* (Sapotaceae) (Mahua)

This is a perennial tree found in Central and South India. Its oil when admixed with grains gave protection against storage pests viz., *R. dominica* and *S. oryzae*. Its leaf, bark and seed extracts also exhibited insecticidal and repellent activities in pulse beetle *C. chinensis*. Application of mahua cake to soil reduced incidence of grubs of *Holotrichia insularis* in chillies. Its bark and seed extracts gave protection against *Crocidolomia pavonana* and *Spodoptera litura*. Seed kernel extract minimised the incidence of the whitefly *Bemisia tabaci* and yellow mosaic virus in mung bean. Its seed oil affected the survival of rice green leaf-hopper, BPH and the white backed plant hopper. Spray application of 2% oil thrice at 15 day interval minimized the incidence of the citrus leaf miner *Phyllocnistis citrella*.

10. *Melia azedarach* Linn. (Meliaceae) (China-berry, Pride of India, Dharak, Persian lilac)

This is a perennial tree found in tropical and subtropical areas. Its leaf, bark, fruit and seed extracts and kernel powder and its oil cake have been reported to exhibit repellent, antifeedant, insecticidal and growth inhibiting activities against storage pests and major agricultural pests. Its 2% leaf powder admixed with basmati rice afforded protection against storage pests. Its active components from leaf extracts are a derivative of 'paraisin' and 'meliantin', the latter reported to possess anti-locust activity. The active component 'meliantriol-I' is present in seed oil. Azadirachtin has been isolated from its leaf and fruit extracts.

11. *Nicotiana tabacum* Linn. (Solanaceae) (Tobacco)

Though tobacco was used in insect control as early as 1763, its principal alkaloid was discovered only in 1828. At least 15 species of *Nicotiana, Duboisia hopwoodii* and *Asclepias syriaca* are known sources of nicotine; the chief sources being *Nicotiana tabacum* and *N. rustica*. Twelve alkaloids have been isolated from tobacco and the alkaloid nicotine constitutes 97% of the total alkaloids. Other alkaloids possessing insecticidal activity are nornicotine, neonicotine or anabasine, nicotyrine and metanicotine, of which the last two are comparatively less toxic to insects. Nicotine is obtained from leaves and stems of waste tobacco by steam distillation or solvent extraction. Nicotine in leaves of *N. tabacum* amounts to 2 to 5%, whereas it is very low or negligible in other parts. The alkaloid content is high from 5 to 20% in *N. rustica*.

Nicotine is a non-systemic insecticide having predominantly respiratory action, and slight contact and stomach action. It decomposes relatively quickly in the presence of light and air. Chemical name is: (*S*)-3-(1-methylpyrrolidin-2-yl)pyridine. In its pure form it is a colourless liquid soluble in water and in most organic solvents; when exposed to air it darkens and becomes more viscous. As a nerve poison it is highly toxic to insects. It is toxic to man by skin contact and inhalation. Its acute oral LD_{50} for rat 50-60 mg/kg; dermal for rabbit 50 mg/kg.

The commercial product is nicotine sulphate containing 40% alkaloid. It was patented in 1908. It is relatively safe and readily water soluble. The standard dosage rate has been 1 part of the material in 500 to 1000 litres of water by weight. In India it was mainly used for the control of cardamom thrips. Tobacco decoction is prepared by boiling 1 kg of tobacco waste in 10 litres of water for half an hour or steeping it in cold water for a day, and the infusion so obtained is made up to 30 litres. Addition of soap at 14 g to 4.5 litres of the infusion will improve its wetting, spreading and killing properties. This is useful in the control of aphids and thrips. Nicotine sulphate 40% solution and 10% DP have been registered in India for export only.

12. *Pongamia glabra* Vent. (Fabaceae) (Pongamia, Kharanjia)

It is a common tree found in coastal India and its root, leaf, flower, seed and fruit extracts in alcohols, their dried powders, seed oil, and oil cake show insecticidal, antifeedant and repellent activities against pests of storage and field crops. Oil at 1% w/w protected cowpea in storage against *C. maculatus.* Pongamia cake applied to soil protected tobacco against the ground beetle *Mesomorphus villiger* in nurseries, and root grubs (*H. insularis)* in chillies and (*H. consanguinea*) in groundnut. Its oil has been reported to be effective against green leaf hopper, leaf folder, BPH and WBPH on rice. The active components constitute 'karanjin' which shows juvenile-mimetic activity and antifeedant activity.

13. *Ryania speciosa* Vahl. (Flacourtiaceae)

It is a native of South America and found in South India. Ryania is obtained from the roots and stems of the plant and its most important alkaloid is 'ryanodine'. It is both a contact and stomach poison, less toxic to mammals than rotenone, more stable and possesses a longer residual action. It has been used for the control of lepidopterous larvae, thrips, etc. Its acute oral LD_{50} for rat is 750 to 1000 mg/kg.

14. *Schoenocaulon officinale* A. Gray (=*Sabadilla officinarum*) (Liliaceae) (Sabadilla)

This is an annual herb found in Mexico, Central and South America. Its active components extracted from bulb and seed contain two to four % of a crude mixture termed 'veratrine' and the alkaloids toxic to the insects in the mixture are 'cevadine' and 'veratridine' which are contact and stomach poisons. The compounds are also highly toxic to mammals and may cause eye irritations and violent sneezing. It has been reported to be effective against lepidopterous larvae, lygaeid bugs, grasshoppers, human lice, etc.

15. *Tephrosia candida* (Roxb.) D. C. (Fabaceae) (White tephrosia)

It is a perennial gregarious shrub found in India. Its seed extracts have been found effective against *Crocidolomia pavonana, Plutella xylostella, Spodoptera litura,* etc. The active components are 'tephrosin' and 'rotenone'. *Tephrosia purpurea* Linn. is a common species in India and its root and leaf extracts have insecticidal and antifeedant activities. The root extract is reported to have the component 'isoflavone' which has antifeedant activity to *Spodoptera litura.*

16. *Thevetia nerifolia* (Apocynaceae)

A native of South America the plant is commonly found in gardens and occasionally found to grow wild near towns and villages in India. It is a small tree with yellow flowers and some-what rounded angular fruits. The kernels possess insecticidal properties. Mashed kernels soaked in water at 15 to 30 g in 10 litres of water and with an equal quantity of soap added was reported to be effective against aphids, whiteflies, thrips, etc. and at higher concentrations against leaf-eating caterpillars.

17. *Vitex negundo* Linn. (Verbenaceae) (Indian Pivet, Chinese chaste tree)

A perennial shrub/tree found throughout coastal states, Bihar and North Eastern regions. Its branch, leaf and seed extracts and seed oil show insecticidal, repellent, juvenile hormone mimetic and antifeedant activities against a wide range of storage pests and lepidopterous larvae. The active components of *Vitex* spp. are viticosterone-E, iridoides, and ecdysones, which show juveno-mimetic activity in insects. The active component from leaf extract of *V. negundo,* 2-heptatriacontanone, inhibits oviposition in stored grain pests such as *S. cerealella, R. dominica* and *S. oryzae.*

◆ Chapter 91

Insect Growth Regulators

The need for new insecticides having both novel modes of action and with useful environmental effects cannot be over emphasised. Juvenile hormone analogues as insect growth regulators fulfill these criteria and many compounds with high juvenile hormone activity have been designed and tested against insects pest. Since the presence or absence of the insect juvenile hormone regulates embryogenesis, metamorphosis, reproduction, diapause, caste/morph determination and even influences sex determination, disruption of these processes is an important defense strategy. The juvenile hormones when applied to developing insects show deranged development showing several external deformities such as formation of supernumerary larvae, larval-pupal or pupal-adult intermediates, all of which result in mortality in a few days. Sometimes adults emerge out of treated larvae, but they fail to mate successfully and cannot lay eggs. The metabolic degeneration of natural JH occurs by enzymatic action of JH esterase. Some of the commercialised JH analogues are methoprene and hydroprene. Recent development of juvenoids fenoxycarb and pyriproxyfen have been found to have increased stability and biological activity. These are applied exogenously as sprays or mixed with insect diets and are known to have sterilising activities, besides their action as ovicides or larvicides. Methoprene has been used in the control of mosquitoes, flies, ants, fleas and so on. A mimic of methoprene, called Kinoprene, has been found to be useful against homopterous insects. Fenoxycarb has been used in the control of several fruit pests of apples, pears and even against *Helicoverpa* armigera in cotton where ovo-larvicidal efficacy was seen.

Many synthetic JH compounds have been available in recent years such as Juvocimene I & II from *Ocimum basilicum* possessing high JH activity. Juvodecimene from *Macropipa* sp. was seen to be effective against the large milk weed bug *Oncopeltus fasciatus*. In India the compounds 'bakuchiol' from *Psoralea corylifolia* and 'karanjin' from *Pongamia glabra* have been isolated. Of interest is a JH-III compound from *Cyperus iria,* which resulted in the juvenalisation of a grasshopper. While most of these products are active, it is clear that JH acts too late to prevent damage, since the immature stages are quick enough to cause damage. The important advantage is that the population of the concerned insect can be minimised, if the juvenoids are applied to the last larval nymphs which may be unable to mate and reproduce. It is here that the UV stable JH analogues such as fenoxycarb and pyriproxyfen herald adequate opportunities as crop protection agents.

The discovery of potential JH antagonists led the way to further intensive work on anti-juvenile hormone compounds called *precocenes*. Two active compounds were isolated from *Ageratum houstonianum,* identified as Precocene I & II. They induced precocious metamorphosis and sterilization, and as they rapidly penetrated the insect cuticle, they were useful in topical treatment. Mode of action of precocene treatment was cytotoxic to the corpora allata, which caused cell death and invasion of the allata by connective tissue. They have been called the 'fourth generation' pesticides. The precocenes induce a variety of physiological and behavioural changes including precocious metamorphosis of the immature stages, sterilisation of adult females, etc. Of interest is the fact that topical application of these compounds shortens the life cycle, resulting in diminished feeding, so that there is less crop damage.

Moulting Hormone Analogues

The moulting hormone produced by the prothoracic glands, called ecdysone, is responsible for normal moulting, growth and maturation of insects. While 20-hydroxy-ecdysone is the moulting hormone, others like 26-hydroxy-ecdysone are also known, and interestingly enough ecdysone-like compounds are also known to occur in numerous plants belonging to the ferns or Pteridophytes and Gymnosperms and some Angiosperms. The ecdysones- Ponasterone A from *Podocarpus* sp. and ecdysterone and Inokosterone from *Achyranthes* sp. as well as ecdysone and ecdysterone from *Pteridium aquilinium* and *Polypodium vulgare* were the firsts to be recognised in plants and since then several hundred plant species were found to possess different ecdysteroids. Increased titres of ecdysone or moulting hormone results on exogenous application of moulting hormone analogues resulting in moulting promotion and death of insects. Interestingly compounds with antiecdysone activity also occur in some plant species and these show inhibitory effects on the development of various insects. 'Plumbagin' from *Plumbago capensis* and 'azadirachtin' from *Azadirachta indica* have been shown to have anti-ecdysone effects, besides 'ajugarin' from *Ajuga* spp. Plumbagin caussed inhibition or delay in ecdysis as it directly acts on the prothoracic glands inhibiting the production of ecdysone. While the juvenility of azadirachtin is well known, there is evidence that it directly acts on corpus cardiacum causing disturbances in ecdysteroid titres.

Interfering with the moulting is a strategy and insect moulting inhibitors such as benzoylphenyl ureas have been known to interfere in moulting of Lepidoptera. Their effect is to generally interfere with moulting and cuticle synthesis. Disruption of feeding and embryonic development are also known. Important benzoylphenyl ureas available as chitin inhibitors in crop protection include diflubenzuron (Dimilin 25 WP), teflubenzuron (Nomolt 50 EC), flufenoxuron (Cascade 10 EC), chlorfluazuron (Atabron 5 EC) and triflumuron. Triflumuron at 0.01% and diflubenzuron at 0.02% caused 100% mortality to the Babul defoliator *Euptroctis lunata* larvae within 20 days of application in Pakistan. In India, diflubenzuron at 75-100 g a.i./ha was found effective against *Crocidolomia pavonana* on radish. Diflubenzuron at 300 g a.i./ha provided control of larvae of *Helicoverpa armigera* on chickpea three days after application. Flufenoxuron and chlorfluazuron both at 60 g a.i./ha were effective seven days after application against *H. armigera* on gram. Lufenuron 5 SC and diflubenzuron 25 WP are effective against larvae of *Plutella xylostella* on cabbage.

Benzoylphenyl Ureas: Following are some insect growth regulators derived out of benzoylphenyl ureas.

Buprofezin

Buprofezin, $C_{16}H_{23}N_3OS$, is 2-*tert*-butylimino-3- isopropyl - 5 - phenylperhydro - 1,3,5 - thiadiazin -4– one. Oral LD_{50} for rat > 2000 mg/kg; dermal for rat >5000 mg/kg. It has contact and stomach action. Effective against mealybugs, whiteflies, scales, planthoppers, etc. The eggs laid by treated insects are sterile.

Chlorfluazuron

It is 1-[3,5-dichloro-4-(3-chloro-5-trifluoromethyl]-2-pyridyloxyphenyl]-3-(2,6-difluoro-benzoyl) urea. The technical grade chemical are colourless crystals and its LD_{50} for rat is >8500 mg/kg. It is effective against lepidopterous pests of cotton and other crops.

Diafenthiuron

Diafenthiuron, $C_{23}H_{32}N_2OS$, is 1, *tert* butyl -3 - (2,6-di-isopropyl - 4 - phenoxyphenyl) thiourea. Oral LD_{50} for rat 2068 mg/kg; dermal for rat > 2000 mg/kg. It is an acaricide/ insecticide having contact and stomach action and some ovicidal action. It is effective against whiteflies, aphids, leafhoppers, diamondback moth, etc. Safe to the beneficial in-sects.

Diflubenzuron

Diflubenzuron, $C_{14}H_9ClF_2N_2O_2$, is 1-(4-chlorophenyl)-3 - (2,6 - difluorobenzoyl) urea. Oral LD_{50} for rat > 4640 mg/kg and dermal for rabbit >2000 mg/kg. It is effective against most leaf feeding larvae at 25-75 g a.i./ha and at 50 – 150 g a.i./ha against cotton bollworms. Non-toxic to predators and bees. Diflubenzuron 25% WP formulation is registered in India. Diflubenzuron is also used in control of fly larvae by topical treatment of the upper layer of the breeding medium at 20-40 g 25WP in water to cover 10 m^2 of surface area and repeated after two to three weeks. This is ideal for minimising housefly nuisance in poultry units. It is also used for the control of larvae of mosquitoes, biting midges and gnats. The dosages of 25 WP recommended for mosquito larval control for 100 m^2 of surface area are: 1-2 g for clear surface water and 2-4 g for polluted surface area; 4 g for 1000 in closed systems with standing water.

Lufenuron

Lufenuron, $C_{17}H_8Cl_2F_8N_2O_3$, is (*RS*)-1 [2,5-dichloro-4-(1,1,2,3,3,3 - hexafluoropropoxy) phenyl] - 3 -2,6-= difluorobenzoyl urea. Oral LD_{50} for rat > 2000 mg/kg; dermal for rat > 2000 mg/kg. It controls beetle grubs, lepidopterous larvae, fleas on pets and cockroaches. Formulation is 10%EC. At 30-60 g a.i./ha is effective against DBM on cabbage.

Novaluron

Novaluron, $C_{17}H_9ClF_8N_2O_4$, is effective against larvae of insects belonging to the order Lepidoptera, Coleoptera, Homoptera and Diptera. Its acute oral and dermal LD_{50} for rat is >5000 mg/kg. Formulation is 10% EC or SC. It is effective against cotton bollworms and DBM on cabbage at 50-100 g a.i./ha.

Teflubenzuron

It is 1-(3,5-dichloro-2,4-difluorophenyl)-3-(2,6-difluorobenzoyl)urea. Technical is white to greyish crystalline solid and its acute oral LD_{50} for rat is >5000 mg/kg; dermal > 2000 mg/kg. Effective against lepidopterous and coleopterous larvae and larvae of mosquito and fly.

Triflumuron

It is 2-chloro-N-[[[4-(trifluoromethoxy)phenyl]amino]carbonyl]benzamide. The technical grade chemical is a colourless powder and its acute oral and dermal LD_{50} for rat is >5000 mg/kg.

Other Classes of PGRs are:

Flufenoxuron

Flufenoxuron, $C_{21}H_{11}ClF_6N_2O_3$, is 1-[4-(2- chloro-α,α,α trifluoro-p-tolyloxy)-2 fluoro-phenyl]-3-(2,6 -difluorobenzoyl) urea. It belongs to the class Acylurea. Acute oral LD_{50} for rat > 3000 mg/kg; dermal for rat >2000 mg/kg. It is effective against a wide range of insects. Its 10% EC formulation at 75–100 g a.i./ha is effective against cotton bollworms.

Pyriproxyfen

Pyriproxyfen is 4-phenoxyphenyl *(RS)*-2-(2pyridyloxy)propyl ether. The technical grade chemical consists of colourless crystals. Its acute oral LD_{50} for rat is >5000 mg/kg; dermal (rabbit) >2000 mg/kg. Effective against a wide range of pests particularly scales and white/ flies on cotton and citrus.

Tebufenozide

It is N-tert-butyl-N'-(4-ethylbenzoyl)-3,5-dimethylbenzohydrazide. Its acute oral LD_{50} for rat is >5000 mg/kg; dermal >5000 mg/kg. It is an insecticide against lepidopterous larvae and useful in forestry pest control as it maintains the natural populations of beneficial and predatory and parasitic insects.

◆ Chapter 92

Principles of Toxicology of Insecticides

The term toxicology is commonly used in the medical and veterinary fields wherein food and organs are analysed for toxic substances in cases of poisoning by chemicals. In the field of agriculture, it is related to the application of toxicants on animals.

In toxicology work it is possible to access the response of an organism to a given treatment in a variety of ways. By means of the probit and the dose metameter a linear equation could be calculated by which the relationship between mortality and concentrations of the toxicant to which the organism is exposed could be arrived at. In 1952* Finney has given the methods of computation. The concentration required to bring about 50% mortality is known as median lethal dose, LD_{50}, which forms the general criterion for the acute toxicity of a solid or liquid compound. The median lethal dosage is the amount of the toxicant required to kill 50% of a test population and is expressed in terms of milligrams of the substance of toxicant per kilogram body weight (mg/kg) of the animal, usually rat, when treated orally. As the test animal is usually rat and sometimes rabbit it is also referred to as the mammalian toxicity. The acute oral LD_{50} values for rat in case of a few chemicals are as follows; potassium cyanide 1, phorate 3.7, methyl parathion 14-24, phosphamidon 28, phosalone 135, fenitrothion 250, malathion 2800, etc. The amount of toxicant required to be placed on the skin to cause death of 50% of test population is referred to as acute dermal LD_{50}. The acute oral and dermal LD_{50} values for rat for the various chemicals are furnished under the respective chemicals dealt with elsewhere in this book. It must be understood that higher the value of LD_{50}, lesser is the toxic nature of the chemical. In the case of insects, the LD_{50}, value is expressed in terms of micrograms of the toxicant per gram body weight of the insect. The toxicity of a poison shows astonishing variation to

* Finney, D.J. 1952 *Probit Analysis,* Cambridge University. Press, Cambridge

different species of insects and therefore tests may be required against each species to assess its usefulness in pest control.

Acute toxicity refers to the toxic effect produced by a single dose of a toxicant whereas chronic toxicity is the effects produced by the accumulation of small amounts of the toxicant over a long period of time. The single dose in the latter case would produce no ill effect.

The term median lethal concentration, LC_{50}, is expressed in terms of percentage of the toxicant required to cause 50% kill of the population of a test animal. It is usually determined by a Potter's Tower Test and probit analysis.

The term I_{50}, refers to the concentration of a toxicant required to inhibit 50% of the enzyme (usually cholinesterase) of a test organism. It is determined under *in vitro* conditions. The values indicate the potential toxicity of organophosphates and carbamates which are potent enzyme inhibitors The term RL_{50}, i.e. Residual Life 50%, commonly referred to as half life of a chemical, indicates the time required for half of the initial deposit to dissipate.

1. BIOASSAY OF INSECTICIDES

Crop protection chemicals are evaluated in the field for their efficacy and performance under conditions of maximum variation in degree of infestation, variety, climatic conditions, etc., and this involves repeating the trials over a number of times and seasons, elaborate recording of observations and high cost in addition to the process of evaluation being slow. But it is essential to eliminate the variable as far as possible and assess the inherent toxicity affecting the biological activity of the compounds using live organisms. This involves laboratory investigations wherein the variable factors tested are the amount of the toxicant to which the organism is exposed and the time of exposure. Therefore, bioassay refers to the study of response of the individual organism exposed to the toxicant.

Bioassay is very easy to perform. It is simple, sensitive, and reliable and does not require any sophisticated equipment. In the field of agricultural entomology bioassay is useful for comparing the efficacy of various insecticides (LD_{50}, LC_{50}, etc.) and in residue analysis. In bioassay, a variety of sensitive organisms are used. These include *Drosophila melanogaster, Musca domestica, Bracon brevicornis, Tribolium castaneum,* etc., which can be multiplied under laboratory conditions. For a more sensitive detection photomigration method using mosuqito larvae or suspension method using water flea *Daphnia* sp. is being employed. Other methods followed are direct feeding method and dry film method. All these methods involve two steps, viz., construction of a standard dosage mortality curve and bio/determination.

Bioassay can be carried out using *Drosophila melanogaster* as the test organism and adopting dry film method for estimating residues present in products at various periods after application of the chemicals.

Potter Spraying Tower: In the 1930s Charles Potter realised the need for accurate and reproducible laboratory bioassay techniques, to relate the amount of insecticide applied to the resulting effect. He designed an apparatus appropriate for the atomised sprays and deposits used in his stored product studies. He improved the bioassay techniques and developed an apparatus, which could spray insecticide formulations on to a 9 cm diameter target with extreme accuracy and reproducibility. The target could consist of a surface on which insects were kept prior to spraying or on which a residual deposit was required. This apparatus refined over years, known as the Potter Spraying Tower or Potter's Tower, is still used in research laboratories throughout the world.

For flying and crawling insects like cockroaches, mosquitoes and houseflies persistence studies are carried out on different types of surfaces such as glass, wood, mud and cement, which are sprayed with the test insecticide, and on residual film on these surfaces the insects are exposed for 30 minutes and then shifted to recovery chambers for 24 hours, after which the mortality count is made. The satisfactory level of mortality of insects would be more than 90%. The residual toxicity is evaluated at different intervals.

Peet Gredy Chamber

Evaluation of space spray against flying insects is conducted in Peet Gredy Chamber as per standard ISI specification 1824. Mats/Coils are also evaluated in Peet Gredy Chamber for knockdown effect. Aerosols are to be evaluated inside a standard room as per WHO tech. report series No. 206.

2. INSECTICIDE RESIDUES

Most of the food we eat, although treated with agricultural chemicals, contains no residues. But the possibilities of harmful residues in food is clearly of concern to the public. When a pesticide is applied to a crop or the soil it starts to be broken down by the action of light, air, microorganisms and the metabolism of the plants. In a practical situation in certain crops several months can elapse between application of a pesticide and eventual harvest and thus no pesticide residues at all are detectable. In case a pesticide could give rise to a residue, pre-harvest intervals are stipulated on labels approved by the registration authorities to give the pesticide time to break down.

Before being consumed many food/material are stored and/or processed which also reduces residues. Many countries have legislation to regulate the levels of pesticide residues in food material and is guided by the concepts of 'Acceptable Daily Intake' (ADI) and Maximum Residue Levels (MRLs) promoted by the United Nations.

Acceptable Daily Intake (ADI) of a chemical is the daily intake, which, during an entire lifetime, appears to be without appreciable risk, on the basis of all the facts known at the time. It is expressed in milligrams of the chemical per kilogram of body weight. Long-term feeding studies are conducted in animals to establish the highest dose, in milligrams per kilogram of body weight, at which no effect at all is observed i.e. no observed adverse effect level (NOAEL). For humans the ADI is calculated in mg/kg of body weight, generally taken as an average of 60 to 70 kg. It is set at a safe level of at least 100^{th} of the NOAEL noted in the most susceptible test species. This is derived from the assumption that man is 10 times as sensitive as the most sensitive species and the most sensitive man is 10 times more sensitive than the norm.

Maximum Residue Level (MRLs) are estimated from globally generated pesticide residue data, obtained using appropriate good agricultural practice. Pesticide residue is any specified substances in food, agricultural commodities, or animal feed resulting from the use of a pesticide. The term includes any derivatives of a pesticide, such as conversion products, metabolites, reaction products, and impurities, considered to be of toxicological significance.

To avoid serious inconsistencies in MRLs between countries, the Codex Alimentarius Commission of the UN FAO has set up a coordinating committee, which reinforces national guards and provides even more consumer protection in international trade.

Good Agricultural Practice in the use of pesticides is the officially recommended or authorised use of pesticides, under practical conditions, at any stage of production, storage, transport, distribution or processing of food, agricultural commodities, or animal feed, bearing in mind the variations in requirements within and between regions. This takes into account the minimum quantities necessary to achieve adequate control, applied in such a manner that the amount of residue is the smallest amount practicable and which is toxicologically acceptable (WHO, 1988).

The ADI and MRLs are not permanently fixed values and as new data become available, they may be revised. In India the MRL values for pesticides are prescribed under the Prevention of Food Adulteration Act, 1954.

The Indian Council of Agricultural Research established the All India Coordinated Research Project on Pesticide Residues in the year 1984.

3. INSECTICIDE RESISTANCE

Resistance is a characteristic of populations, not of individuals. Within all populations of all species there is genetic variation. Some strains of insects may show a natural tolerance to a particular pesticide, possibly based on an ability to detoxify it by enzyme activity. If such a strain constitutes a sizeable level of the total population, it is that population which will survive a pesticide treatment and go on to multiply. A much higher proportion of its offspring will be resistant to that particular pesticide. Frequent and repeated applications can thus cause resistance to develop at an accelerated process of selection. It is likely to develop rapidly in species, which have numerous generations of offspring within a short time-span.

In 1914 Melander reported about resistance on San Jose Scale to lime sulphur. Quayle in 1916 noticed resistance of California red scale on citrus to hydrogen cyanide. Prior to 1945 thirteen insect and tick species were reported as resistant to arsenicals, selenium, hydrogen cyanide, rotenone, etc. In 1947 resistance to DDT in housefly was reported from Italy and Sweden. By 1960 resistance to organochlorines, organophosphates and carbamates was reported in about 137 species. The development of resistance may be due to genetically induced changes in species-specific behaviour of the insect, and the morphological or physiological nature of an insect species.

Behaviouristic resistance is the ability of a species to avoid doses of toxic substances, which would otherwise be lethal. For example, mosquitoes avoid surfaces treated with DDT.

Sometimes a strain of a species selected by an insecticide compound shows resistance to another insecticide compound of some other group, though the latter was never involved in the selection. This is known as 'Cross Resistance' and has been defined by Grasyson and Cochran in 1968 as 'Resistance to more than one insecticide occurs following exposure to only one compound'. For example, cross resistance has been observed mainly within the classes of the organophosphates and occasionally against DDT and some carbamates.

The most important mechanism of resistance to the organophosphate compounds is the physiological resistance, which is of a complex nature. It relates to the genetically controlled potentiation of enzymatic hydrolysis in the insect. Increase in certain hydrolases alters the relationship between oxidation and hydrolysis to the detriment of the activating oxidation but in favour of the detoxifying hydrolysis mechanisms. In the houseflies resistant to organophosphate the "aliesterases", originally present had been transformed by gene mutation into phosphates which function as degrading enzyme for organophosphates. Housefly strain resistant to malathion metabolised malaxon more rapidly. Similarly the activity of organophosphate metabolising enzymes is attributed to resistance in fenitrothion and methyl parathion. Resistance in organophosphates is exclusively associated with dominant single gene.

The principal mechanism of DDT-resistance in house-flies is the detoxication of DDT to DDE by the enzyme DDT-dehydrochlorinase.

At a global level, insect pests have developed resistance to all major classes of pesticides and will develop resistance to future pesticides as well. The situation in India is enumerated below.

(i) Insecticide Resistance in Public Health Insects: Resistance to DDT was first noticed in India in the year 1952 in the mosquito *Culex fatigans*. Mosquitoes transmitting malaria and other vector diseases were noted subsequently to become resistant to DDT and HCH in various parts of the country.

(ii) Insecticide Resistance in Household Pests: The bedbug, *Cimex lectularius*, was reported to be resistant to DDT in 1953 and subsequently to HCH and few organophosphorus compounds. Human body louse *Pediculus humanus corporis* developed resistance to HCH in 1952 and rat flea *Xenopsylla cheopis* to DDT in 1961. The housefly *Musca domestica nebula* is resistant to HCH and DDT throughout the country.

(iii) Insecticide Resistance in Veterinary Pests: So far only *Boophilus microplus* infesting cattle has shown resistance to lindane in 1963 at Mukteshwar.

(iv) Insecticide Resistance in Agricultural Pests: First instance has been resistance noticed in Singhara beetle, *Galerucella birmanica*, at Delhi to HCH and DDT in 1963. The next instance being resistance to HCH in *Spodoptera litura* in 1965 and subsequently to malathion, endosulfan and carbaryl. Similarly the diamondback moth. *Plutella xylostella*, has been reported to be resistant to DDT, parathion, fenitrothion, cypermethrin, fenvalerate, deltamethrin and quinalphos. Resistance to endosulfan and tolerance to malathion and dimethoate has been noticed in *Lipaphis eryisimi* in some areas of Punjab.

The failure to control *Helicoverpa armigera* on cotton in Andhra Pradesh during 1987-88 was traced to the development of a high degree of resistance to synthetic pyrethroids such as cypermethrin and fenvalerate in this pest species. It has been shown that the pyrethroid resistance in *Helicoverpa* is due to increased detoxification in resistant population.

(v) Insecticide Resistance in Stored Grain Pests: The flour beetle *Tribolium castaneum* was first noticed in 1971 to exhibit resistance to DDT and malathion, and subsequently to lindane and phosphine. Resistance to malathion, lindane and phosphine in the rice weevil *Sitophilus oryzae*, to malathion and lindane in the grain beetle *Oryzaephilus surinamensis*, to phosphine in khapra beetle *Dermestes granarium*, and to lindane in the Leather beetle *Dermestes maculatus* are other instances reported from India.

4. INSECTICIDE RESISTANCE MANAGEMENT (IRM)

Since 1984 the threat of insecticide and acaricide resistance development was well known. In the recent years producers, academics, government officials, advisers, distributors and growers are working together in an attempt to halt resistance development. In many instances, these groups are brought together by the industry through the Insecticide Resistance Action Committee (IRAC), a GIFAP working group founded in 1985. Resistance management forms integral part of IPM and will not succeed unless growers and distributors can be persuaded to change the ways in which they select and use agrochemical products. In India the pesticide industry as well as the agricultural universities have been suggesting various ways to contain this problem, particularly with regard to *Helicoverpa armigera*, a serious pest of cotton. A number of strategies have been employed for IRM: Judicious use of pesticides resorting to application based on monitoring the pest population in the field; use of synergist which will enhance the toxicity of a given insecticide by inhibiting the detoxification mechanism; alteration of chemicals with unrelated mode of action; a product containing two or more compounds with different modes of action; sticking closely to the recommendations on dose rates and time of application; varying sowing dates to avoid peak risk periods; use of crop varieties resistant to the pest species; use of biological control; strict crop hygiene which removes sources of infestation; and crop rotation to avoid the build-up of the pest species.

◆ Chapter 93

Pesticides and the Environment

The atmosphere is polluted by smokes, acid and sulphur dioxide vapours from factories, carbon monoxide from the exhaust gases emitted by motor vehicles, and by the pesticides. Water pollution is brought about by effluents from factories (the organic matter in such contaminated water is broken down by bacteria which consume oxygen and the oxygen demand is usually tested by 'biochemical oxygen demand' or B.O.D. test) some of which may have toxic substances like metalic zinc and copper, by crude oil mostly in seas and beaches, and by pesticides. Pollution of soil is by all agents that pollute water.

Pollution of environment by pesticides is the result of extensive and intensive cultivation necessitating continuous and more frequent use of pesticides. Pollution was not as serious a problem with the earlier phytogenous and inorganic pesticides as with the organic pesticides, some of which are highly persistent or contaminate the ground water.

Among the different kinds of pesticides organophosphorus compounds like parathion and fenthion quickly breakdown and cease to be dangerous. Birds entering a treated area a few hours after application usually survive. Damage to wild life due to methyl parathion is negligible. Systemic poisons are the least contaminants of the environment as they are degraded quickly into harmless compounds. However, the persistent chemicals such as the chlorinated hydrocarbons are mostly responsible for pollution. They are desirable with reference to the control of insects as their effects remain for a long time undesirable as regards safety to man and animals for the same reason, for a relatively long time has to be passed before consuming a treated produce to avoid possible harmful effects.

Persistent pesticides were known and in use ever since chemicals were employed in pest control. The early such pesticides were inorganic compounds containing arsenic, selenium, mercury, lead, zinc and flourine. But they were in limited use. The real pollution problem associated with the persistence of pesticides started with the use of DDT and other organochlorines. These pesticides were effective against a variety of crop pests and insect and arthropod carriers of various human and animal diseases and were cheap. Large amounts of them were produced and utilised every year. In the recent years usage of such persistent chemicals has either been withdrawn or restricted.

1. PESTICIDE RESIDUES IN SOIL

Pesticides reach soil as a result of direct application to it or by drifting during dusting and spraying to foliage or washed down by rains after application.

From soil the persistent chemicals enter into soil invertebrates or water, or are broken down by microorganisms and physical factors. Such chemicals are mostly DDT and dieldrin (aldrin also breaks down in soil to dieldrin). DDT and dieldrin are reported to be more prominent soil contaminants in western countries, perhaps because of their large scale and indiscriminate use. The persistence of chemical in soil is influenced by various factors:

(i) the granular formulations persist longer than emulsions which again persist longer than wettable powders;
(ii) heavy clayey soil retain pesticides longer than light sandy ones and both organochlorines and organophosphates persist longer in acid than in alkaline soils;
(iii) higher the organic matter and clay mineral content in a soil longer is the persistence of a chemical;
(iv) higher the temperature and soil moisture less is the persistence;
(v) the break down of insecticides is more in soils having microorganisms than in sterile soils.

The presence of persistent chemical in soil does not itself constitute a great hazard to environment except that it forms a reservoir of chemical which moves into plants grown on it and into birds feeding upon earthworms and other soil invertebrates having deposits of the chemical in their tissues. When such birds survive their flesh and eggs contain residues of such chemicals.

2. PESTICIDE RESIDUES IN WATER

Pesticides reach water in lakes, ponds, tanks, rivers and streams from application of the same in mosquito control, deposits from aerial spraying of cultivated crops, as a surface run off from soil treated with the chemical, from disposals and wash off of insecticide containers, etc. Due to the absorption of the chemicals by bottom sand mud, plankton, aquatic plants and invertebrates and of the break down due to hydrolysis, toxic concentrations in water seldom build up. However, the two main hazards of residues in water are the deposition of chemicals in the bodies of fishes, which are effective filters of suspended particulate matter and in the bodies of aquatic organisms that form the food for the fish and as a result of both of these more chemical gets deposited in the fishes than is found free in water. The accumulation of pesticides in fishes is of great significance because they form food for the man and birds.

3. PESTICIDES IN THE BIOTA

(a) In plants Plants retain pesticides on their surface or in tissues as a result of chemical control of pests. Organophosphorus compounds and systemic poisons are soon broken down but organochlorines like dieldrin, are retained for relatively long periods. It is important that crops used for human or animal food should not contain residues of pesticides and hence tolerance levels that can be permitted in crops used for food have been fixed for most chemicals.

(b) In bird Residues of organochlorines occur in the tissues and eggs of many species of birds and these residues might have accumulated from their food, mainly from fish and also from grains, leaves, etc. The birds accumulating lethal doses of the poison may get killed. This accumulation is passed on to any predatory and scavenger birds feeding upon them.

It has also been reported that residues of organochlorines in their tissues lower the vitality of chicks and eggs. However, birds lose the chemicals when they are no longer exposed to them.

(c) In Food Pollution is through application of persistent pesticides just before harvest or during storage. The important group of chemicals that tend to persist in plant tissue and are transferred to man and animals include DDT, HCH, and dieldrin in the body of animals as they get accumulated in the fat tissue and are present in milk and dairy products.

(d) In man DDT is the most common pesticide than all other organochlorines present in human tissue. It has been said that, at present, the average amount of DDT present in human body is 5 to 10 ppm. The other common residues are from aldrin and dieldrin. Organochlorines can be transferred from the mother to foetus so that babies may be born with some pesticide chemical in their bodies, and milk from such mothers will also contain the chemical that together will accumulate in the babies' bodies. However, these residues have not been proved to cause any immediate harm to man but the possible long-term effects need further studies. Fortunately in tropical country like ours the chances of breakdown of chemicals into harmless compounds are more.

The possible pollution of human and cattle food can be minimised in several ways:

1. Using less persistent chemicals like organophosphorus compounds and carbamates, which are equally or more effective than the persistent organochlorines against the pests they are usually used; however, they are more toxic to mammals than organochlorines and so adequate precautions have to be taken during and immediately after application.
2. Better use of pesticides like applying them just around plants instead of broadcasting all over the planted area, seed dressing, seedling dips, using granular formulations on or around the plants or in furrows, etc.
3. Particular microorganisms in soil degrade particular pesticides; for example a strain of the bacillus *Nocardia alba*, degrades parathion to the extent of 61% in eight days under optimum conditions. It has been found that the break-down of particular chemical is faster in soils treated with the same pesticide in the previous season because of the presence of the appropriate microorganisms in the soil. The possibility of introducing such microbical cultures to soil to hasten the break-down of pesticide will be an interesting field of exploration.
4. Resorting to control of pests through ways other than chemical, like biological method.

◆ Chapter 94

Handling of Pesticides

With the increased use of pesticides in the control of pests, greater care in handling and using these chemical compounds has become necessary since most of them are toxic to human beings and domestic animals. In largescale use of pesticides hazards may arise due to accidental or intentional poisoning, operational hazards during application, post-application hazards due to residues, etc.

Based on the mammalian toxicity, pesticides are generally classified as:

(i) non-hazardous pesticides (pyrethrum products, sulphur, etc.);

(ii) moderately hazardous pesticides (DDT, malathion, fenitrothion, carbaryl, etc.), and

(iii) dangerous pesticides (aldicarb, parathion, zinc phosphide, etc.).

1. GENERAL PRECAUTIONS

The following general precautions should be followed in handling the pesticides:

1. The pesticides should be retained in their original labelled containers.
2. The pesticides should be kept in a locked cupboard or closet so as to be out of reach of children, pets and other domestic animals.
3. Pesticides should not be stored near food stuffs or medicines.

4. The labels on the containers should be carefully read and the instructions strictly followed.
5. A separate knife should be kept for purposes of opening bags or tin containers.
6. Empty containers of pesticides should be destroyed and should not be used for any other purpose.
7. Inhaling of pesticide sprays or dusts when mixing or applying them should be avoided.
8. Dusting or spraying should never be done against the wind and when the wind is high. These operations should preferably be done in the early hours of forenoon.
9. Protective clothing and devices should be used while handling pesticides to avoid exposure to sprays or drifts.
10. Spilling of pesticides on skin or clothing should be avoided.
11. While preparing spray solutions bare hands should never be used for mixing the solution. It is advisable to use a long-handled mixer to avoid splashings.
12. While handling pesticides, smoking, eating or drinking should be avoided.
13. After application hands and other exposed parts of the body should be thoroughly washed with soap and water and new clothes should be worn.
14. The nozzles or other parts of equipments should not be blown by mouth and contaminated washers from spray appliances should be buried.
15. The appliances and empty containers should not be washed near a stream or well, as it will contaminate the water.
16. The clothes worn during spraying or dusting operations should be washed after each operation.
17. Persons engaged in handling of pesticides should be checked periodically by a physician.
18. In the case of any suspected poisoning due to pesticides the nearest physician should be called in immediately.

2. FIRST AID PRECAUTIONS

In case of pesticide poisoning call a physician immediately. Awaiting the physician's arrival, apply first aid.

1. *Swallowed poisons*: Remove poison from the patient's stomach immediately by inducing vomiting. Give common salt 15 g in a glass of warm water as an emetic and repeat until vomit fluid is clear. Gently stroking or touching the throat with the finger or the blunt end of a spoon will aid in inducing vomiting when the stomach is full of fluid. If the patient is already vomiting do not give emetic but give large amounts of warm water and then follow the specific directions suggested

2. *Inhaled Poisons*: Carry the patient (do not let him walk) to fresh air immediately. Open all doors and windows. Loosen all tight clothing. Apply artificial respiration if breathing has stopped or is irregular; avoid vigorous application of pressure to the chest. Prevent chilling. Wrap the patient in a blanket. Keep the patient as quiet as possible. If the patient is convulsing, keep him in bed in some dark room. Avoid jarring noise. Do not give alcohol in any form.

3. *Skin contamination*: Drench the skin with water. Apply a stream of water on the skin while removing clothing. Cleanse the skin thoroughly with water. Rapid washing is most important for reducing the extent of injury.

4. *Eye contamination*: Hold eyelids open. Wash the eyes gently with a stream of running water immediately. Delay of even a few seconds greatly increases the extent of injury. Continue washing until physician arrives. Do not use chemicals. They may increase the extent of injury.

5. *Prevention of collapse*: Cover the patient with a light blanket. Do not use a hot water bottle. Raise foot of bed. Apply elastic bands to arms and legs. Give strong tea or coffee. Hypodermic injection of stimulants, such as caffeine and epinephrine. Fluid administration of dextrose 5% intravenously. Blood or plasma transfusion. Do not exhaust the patient by too much or too vigorous treatment.

3. ANTIDOTES

A. General Antidotes

1. Removal of Poison: Remove poisons by inducing vomiting.
2. The "Universal Antidote": A mixture of 7 g of activated charcoal, 3.5 g of magnesium oxide and 3.5 g of tannic acid in half a glass of warm water may be used to absorb or neutralise poisons. This mixture is useful in poisoning by acids, liquid glycosides and heavy metals. Except in cases of poisoning by corrosive substances it should be followed by gastric lavage.
3. Gastric Lavage (Removal of Stomach contents): Lavage is the most important method for removing poisons from the stomach.

4. Demulcents (Substances having soothing effect): After the stomach has been emptied as completely as possible, give one of the following:

(i) Raw egg white mixed with water;

(ii) Gelatine 9 to 18 g dissolved in 570 ml of warm water;

(iii) Butter;

(iv) Cream;

(v) Milk;

(vi) Mashed potato;

(vii) Flour and Water.

B. Specific Antidotes for some Pesticides

The following emergency treatments are prescribed for poisoning by some specific pesticides.

DDT and other organochlorines: If swallowed, give 'Universal Antidote', followed by gastric lavage. Then give 28 g of magnesium sulphate (Epsom salts) in a glass of water, followed by hot tea or coffee. Inject 10 ml of 10% calcium gluconate intravenously. If necessary, inject phenobarbital 0.1 g intravenously. Feed the patient with rich carbohydrate and calcium diet to prevent liver damage.

Aldrin and Dieldrin: If skin is contaminated, wash immediately with soap and water. If swallowed, give emetic and repeat until the vomit fluid is clear. The physician may administer phenobarbital or barbiturates as for convulsion therapy. Have the patient lie down and keep quiet.

Organophosphorus compounds: If the patient has blurred vision, abdominal cramps and tightness in the chest, give two tablets of atropine (each 1/100 g). Administer artificial respiration in case of respiratory failure. Do not give morphine.

Zinc phosphide: If the patient has taken the poison within 24 hours, proceed as follows: Stir one teaspoonful of mustard powder into a glass of warm water and make the patient drink it. After vomiting has stopped, give the patient 5 g of potassium permanganate dissolved in a glass of water. After ten minutes, have the patient drink a solution made of half teaspoonful of copper sulphate in a glass of water; and fifteen minutes after treatment give the patient a solution made by dissolving one tablespoonful of magnesium sulphate

(Epsom salts) in a glass of water. If the poison has been taken earlier than 24 hours, start giving potassium permagnate solution to drink and continue with the treatment as stated alone.

Bromadiolone: Antidote is Vitamin K_1. Administered orally or intramuscularly. Repeat as necessary.

◆ Chapter 95

Plant Protection Appliances

The desired effects of a pesticide can be obtained only if it is applied in an appropriate time and in a proper method. The method of application will depend upon the properties of the pesticide, the nature of the pest or pests to be controlled and the site to which the pesticide is to be applied.

The important methods of applying pesticides are dusting and spraying. The former method has been in vogue for longer time than the latter. However, spraying is the most common method now because of certain disadvantages associated with dusting like:

(i) the loss of chemical due to drift and consequent pollution risk;

(ii) less efficient deposition of dust particles on plant surface resulting in decreased efficiency in pest control;

(iii) tendency of the chemical in dust formulation to separate itself from the carrier, if its density is widely different from that of the latter, resulting in loss of chemical; and

(iv) the increased toxic hazard to operator.

However, dusting will be an useful way of application of chemicals in areas like the vast stretches of unirrigated crop tracts with limited water supply, in hilly terrains and also in case of control of pests occurring in crops just before harvest like earhead bugs and caterpillars. There are certain disadvantages with dusting over spraying. They are requirement of less labour for the operation, coverage of a larger extent of crop per day than with spraying, and light weight of dusting appliances with less risk of corrosion.

A. DUSTING AND DUSTERS

1. General Principles

Most insecticidal dusts are made of very fine particles that may pass almost completely through a 325 mesh sieve of 44 micron aperture. Therefore, the dust particles when falling free in air either slowly settle down due to gravity or drift for long distances due to wind. The rate of deposition is directly proportional, and of drift inversely so, to the size of the particle. However, dust particles not only differ greatly in their size and shape but also many tiny particles agglomerate together during the dusting operation and hence it is very difficult to forecast the pattern of their settling and drift. The settling velocity of the particles is also influenced by the density of the dust diluent and the presence of dust conditioners such as stabilisers and fluffing agents.

It is often stated that the ability of dust particles to be deposited on plant surface is influenced by the electrostatic charge of dust particles. Leaf surfaces generally have a negative electrostatic potential. The charge on the dusts can be increased by friction or by passing the dust particle through a flow of positive ions. Such charged dusts agglomerate less, adhere to the plant surface better and distribute more evenly on both sides of leaves. However, as regards retention by the target area it is no better than the uncharged dust, as the charge is lost quickly. During spraying charged spray particles repel themselves resulting in increased swath width.

There are other significant properties of dusts that affect their storage, application, deposition and adherence. These include the bulk density, indicating the degree of fluffiness, flowability, hardness of particles causing abrasion of equipment, shape of particles, for irregularly shaped particles flow slowly, and sorption resulting in caking due to absorption or adsorption of moisture.

In general, if the amount of active ingredient of the pesticide applied per unit area is same the efficiency of pest control is unaffected irrespective of the quantity of the formulation used; for instance, 100 kg of 1% dust is as effective as 20 kg of 5% or 10 kg of 10% formulation, provided there is adequate coverage and distribution.

2. Dusters

Appliances that are used for applying dry dust formulations of pesticides are called dusters. They are either manually or power operated. All dusters consist essentially of a hopper, which usually contains an agitator, an adjustable orifice or metering mechanism and delivery tubes. A rotary fan or a bellows provides the conveying air.

(a) Manually Operated Dusters

It comprises of package dusters, plunger dusters, bellows dusters, rotary dusters and knapsack dusters, of which the last two are commonly used.

Rotary dusters : They are also called crank dusters and fan type dusters. They vary considerably in design and may be shoulder mounted, back mounted or belly mounted. Basically a rotary duster consists of a blower complete with gear box and a hopper with a capacity of about 4-5 kg of dust. The duster is operated by rotating a crank and the motion is transmitted through the gear to the blower. Generally an agitator is connected to one of the gears. An adjustable feeding mechanism is also provided. The air current produced by the blower draws the dust from the hopper and discharges out through the delivery tube, which may have one or two nozzles. Rotary hand dusters are largely used in India for dusting field crops, vegetables, small trees and bushes in orchards. The efficiency of these dusters is 1 to 1.5 ha per day.

Knapsack dusters: This consists of a dust container of 2.5 to 5 kg capacity through which air current is blown by means of bellows, which are worked by hand lever attached to one side of the container. The air blast takes the dust into delivery pipe and discharges out in an intermittent manner. Knapsack dusters are designed to be carried on the back of the operator and are more suitable for low crops and for spot applications.

(b) Power Operated Dusters In addition to the usual components like a hopper, agitator fan, discharge tubes, boom and nozzles of manually operated duster, a power operated one has a petrol engine to produce power to operate.

B. SPRAYING AND SPRAYERS

1. General Principles

The spray fluid may be a solution, an emulsion or a suspension of the toxicant. Its liquid phase is usually water or less frequently a light oil. However, water is not a good carrier for pesticide because of the hydrophilic nature of the insect cuticle, insolubility of the same and break down by hydrolysis of certain other insecticides in water and of its evaporation from small droplets thus making the particles light and hence drift. Yet water is the carrier in high volume sprays though it is minimised in low volume (LV) sprays and eliminated in ultra-low volume (ULV) sprays. To obtain an effective control of the pest, the toxicant has to be well distributed and to meet this requirement the spray fluid is broken down to fine droplets. In different types of sprays the droplets vary from 30-400 microns in size. The size also varies greatly at different distances from the point of emission from the sprayer.

The atomisation of the spray fluid is accomplished by either forcing the spray fluid under pressure, which may be hydraulic or pneumatic, through a nozzle or by emitting a jet of spray fluid into a high velocity air stream.

Insecticidal sprays are described as 'aerosols' or 'space sprays' when the spray is applied as a cloud or mist of droplets which remain suspended in space for controlling flying insects that pass through it and as 'residual sprays' when it is applied to surfaces of plants, animals or structures frequented by insects. With residual spray to control sedentary insects like scales and mealy bugs a complete coverage of plant surface is necessary but to control mobile insects a random coverage is sufficient.

Depending upon the quantity of spray fluid required per unit area, the sprays are described as high volume sprays, low volume sprays and ultra low volume sprays. With high volume spraying or full coverage spraying 400 to 1000 litres of spray fluid is required to cover a hectare of field crops. The pesticide is diluted with water. The spray droplets are large enough so that, upon emission from the sprayer, they gain momentum and reach the target. On the target surface the particles coalesce and reach the point of run off. This results in wastage of chemical. By reducing the quantity of water used in spray fluid or totally eliminating it, the cost of application can be lowered and this is accomplished in low and ultra-low volume sprays. Due to this advantage the LV and ULV sprays have gained much popularity. With LV spray the concentration of the toxicant is increased by 1-25 times with corresponding decrease in total quantity of spray fluid. Hence it is also known as concentrate spray. About 5 to 400 litres of spray fluid is used to cover a hectare of field crop and the droplet size varies from 70 to 150 microns. An intermediate range of two to four times increase in concentration of the toxicant with corresponding decrease in the volume of the total spray fluid is described as semi-concentrate or semi-low volume spray. In ULV spray the pesticide is applied undiluted, in small quantities, usually less than 5 litres/ha. The size of the droplet varies from 20 to 150 microns. In the concentrate sprays air is the carrier of the toxicant and not water as in high volume spraying. The pesticide liquid is fed into air stream flowing at high velocity. The atomisation is more with increase in air volume.

In LV sprays there is never a full coverage or full wetting of the foliage and the droplets never coalesce nor reach a point of run off. The advantages with LV sprays are:

(i) Less time and cost are involved in transport of water, and hence the cost of application is minimised;

(ii) the spraying operation is speeded up; and thus timely control of pests is possible; and

(iii) the weight of appliance is much less.

However, there is a disadvantage in that there is risk of wastage of chemical due to evaporation of water and drift of the chemical because of the smallness of droplets. To minimise this loss the LV spraying should be carried out in still air with wind velocity not exceeding 8 km/h.

2. Parts of a Typical Sprayer

A sprayer consists of definite parts, each with a definite function. The important parts are described below.

Tank: The spray fluid may be contained in a tank that is built in the sprayer as in the case of any knapsack sprayer or in a separate container as in the case of pedal pump. A built-in tank should be made of a non-corrosive metal or thick polyethylene and its capacity may range from less than one litre as in a pneumatic hand sprayer to 10 to 25 litres in a knapsack sprayer or mist blower and up to 200 litres in large sprayers. The tank should be provided with a good agitator, a strainer in the filter hole and a drain plug at the bottom to drain away the liquid after use and after cleaning.

Agitator: If the spray fluid is a solution of the toxicant it does not settle and hence does not require to be agitated. But emulsions and suspensions of wettable powders settle slowly and quickly respectively. Hence such fluids require to be agitated to prevent uneven spray strengths. Most sprayers with built-in tanks have paddle like agitators that rotate in the tank and keep the material uniformly dispersed. In the case of sprayers with no such built-in tanks the return flow of excess spray fluid from the pump helps to agitate the fluid in the separate container. But this does not evidently happen in sprayers when the outflow of liquid is equal to the inflow and in such cases frequent mechanical stirring of the fluid with a stick or rod becomes necessary.

Filters: Series of filters are provided in sprayers to strain off dirt and coarse particles from entering the nozzle and blocking the flow. Even partial block of nozzles will disturb the spray pattern and distribution. In addition to the coarse particle filter at the entrance of the tank, filters are provided in the line between the tank and the pump. Filters are also present between the pump and the boom of spray lance and also in individual nozzles.

Pump: Pumps are necessary for feeding the nozzle for delivery tubes with appropriate quantities of spray fluid for atomisation. While selecting a pump during construction of a sprayer factors like the amount of material to be delivered per minute and the pressure that must be obtained on the delivery side of the pump should be taken into consideration.

It is important to realize that in a sprayer the pump is the most vital and expensive component.

Air pumps, also known as pneumatic pumps, are used in compressed air sprayers. They force the air into the tank containing the spray fluid, which is brought under pressure. They do not pump the liquid directly.

Direct displacement pumps are of two main types, plunger and rotary. Plunger pumps are also known as piston pumps. Rotary pump consists of two closely fitted gears. Both these types of pumps displace a definite volume of liquid from inlet into the outlet.

Centrifugal pumps are fitted to high pressure booms sprayers with a capacity of 500 litres per minute.

Power source: Petrol engines coupled with the equipment or any separate engine, through power-take-off device, provides power to the power-operated sprayers.

Pressure guage: It is fixed on the discharge line. It helps to assess if other parts of the sprayer are functioning correctly and for adjusting the pressure required for the job.

Valves: The valves are important in any sprayer, because they maintain the direction of flow of the spray fluid. Ball valves, consisting of metal balls sitting perfectly on a circular seat, and spring valves, consisting of a shutter operated by spring, are the two main types used in sprayers.

Hose: Hose pipe is used for conduction of the spray fluid from the sprayer to the lance and, in the case of sprayers with no built-in tank, from the container to the sprayer. A good hose should be light, flexible, durable, non absorbent and oil-resistant. It should not impart friction to the free-flow of liquid through it, for it may result in loss of pressure, though the length and diameter of the hose may also influence such loss. Plastic and nylon hoses are much in use because they are light and cheap.

Spray Lances: They are seamless, detachable brass tubes, usually 90 cm long and have the nozzle or nozzles screwed on to their end.

Spray cut off-devices: To shut off the flow of liquid there is usually a device in the lance. It may be a stop-cock or a trigger mechanism with provision for adjusting the release of fluid either as a cone or as a jet.

Booms: Sometimes a number of nozzles can be arranged in horizontal tube called the boom or spray bar. It is normally coupled with power sprayers. Booms are usually used for treating row crops. Boom-nozzle placement combinations are available for specific jobs.

Nozzles: Nozzle is an important component in a sprayer since it breaks up the liquid issued from the machine into droplets and emit them as a spray. Depending upon the design of the sprayer and of the nozzle the size of droplets varies. Even from the same sprayer with the same nozzle the droplets may be of varying sizes forming, what is described as, a spray spectrum.

Nozzles are of different designs for different rates of discharge and for low pressure and high pressure. Hollow cone nozzles are most commonly used in crop pest and disease control. In this type of nozzle the spray fluid is made to rotate by a whirl plate, also called as swirl plate, by means of slanting holes in it or a spiral screw thread on it. The liquid passes out as a conical sheet, which soon breaks up into droplets forming a hollow cone pattern of spray. On the other hand if the whirl plate is provided with an additional hole in its centre, the fluid passing out through the latter fills up the air core in the centre of the cone and hence a solid cone pattern of spray results. Nozzles producing solid cone sprays are used where even coverage is desired as in weed control and for spot treatment.

A typical spray nozzle consists of a base, a screw cap, a disc or an orifice plate, a washer also called as spacer or seal, and the whirl plate with or without a strainer.

In low volume nozzles the spiral grooves in the whirl plate are very fine, orifice is smaller with a greatly reduced space between the body of the nozzle and the whirl plate. Such a nozzle has a built-in strainer to prevent the entry of coarse and dust particles and plugging of tiny grooves.

Nozzle tip is the most important but least expensive part of the sprayer system. The liquid sprayed takes up a hollow cone, flood, jet or flat fan pattern depending upon the type of nozzle tip used.

The nozzle may be adjustable and suitable for spraying targets, which are not within the reach of man. Adjustments may be done to give a wide angle hollow cone, to a straight solid stream. A sprayer may also carry a double swirl nozzle for spraying in two different directions simultaneously. Double nozzle is suitable for high volume application.

3. Types of Sprayers

The spraying machines may be either manually operated or by power. In either category there are sprayers working with hydraulic pressure or with air (or pneumatic) pressure. In sprayers working with hydraulic pressure, pressure is developed by the direct action on the spray fluid. This pressure forces the liquid through the nozzle. On the other hand in sprayers working with air compression system pressure is developed on the air contained in the spray tank.

(a) Manually Operated Hydraulic Sprayers

1. *Hand Syringe or Garden Syringe*: It is a single acting pump working on the principle of a bicycle pump. It consists of a cylinder or pump barrel, and a plunger or piston. Spray fluid has to be contained in a separate tank. The fluid is drawn either through the nozzle aperture itself or through a separate aperture, provided with ball valve, near the nozzle. The liquid is drawn on the return stroke of the plunger and ejected during the compression stroke. After each ejection the spray fluid has to be drawn in. The spray is made of large droplets and is just like drenching. It is useful for small scale spraying in kitchen garden and pot plants.

2. *Bucket sprayer or Stirrup-pump*: It may consist either of a double acting pump with two cylinders or a single acting pump with one cylinder. The other parts of the sprayer are the plunger assembly, foot valve assembly, hose, lance, nozzle, a stirrup and an adjustable foot rest. The plunger assembly has a plunger shaft, a handle and a travel limitation device. The pump has to be put in a bucket of any container having the spray fluid. In the single acting pump the discharge is discontinuous since the fluid is ejected only during the downward compression stroke, while in the double acting pump the discharge is continuous as the fluid is discharged during both suction and pressure strokes. However, in both cases continuous pumping is necessary. This type of sprayer is useful for spraying small areas.

3. *Knapsack sprayers*: To fit comfortably on to the back of the operator like a knapsack this type of sprayer has a flat or bean shaped tank. The tank has a capacity of 10 to 30 litres and is made of galvanised iron, brass, stainless steel or plastic. It is similar to the bucket type in principle. A lever-handle is provided for operation. It has to be continuously operated with simultaneous operation of the spray lance with the other hand. A mechanical agitator is provided inside the tank and it moves up and down inside the container due to the movements of the pump level. It is preferred for spraying rice crop; it is also used for spraying low crops, vegetables and nurseries.

4. *Rocker sprayer*: It consists of a pump assembly, a rocking-lever, pressure chamber, suction hose with a strainer, delivery hose, cut-off valve and spray lance with nozzle. By rocking movement of the lever, pressure can be built in the pressure chamber and this helps to force the liquid through the nozzle. There is no built-in tank. It can be used for spraying trees and tall field crops.

5. *Foot sprayer or Pedal-Pump*: A pedal-pump consists of a vertical pressure chamber mounted on to a stand and a plunger assembly with the plunger rod attached to a pedal in addition to the other usual components viz., a suction hose with a strainer, a delivery hose with an extension rod and spray nozzle, etc. It has no built-in tank. It works on the same

principle as the rocker sprayer except that the pedal is worked up and down by foot in this case whereas the rocker in a rocker sprayer is operated forward and backward by hand. In both cases continuous operation of pedal or rocker is required to maintain high pressure for uniform spraying. Pedal pump develops a pressure 17-21 kg and a rocker sprayer 14-18 kg/cm^3. It is easy to operate and can be used for spraying agriculture crops as well as small fruit trees. About 1 to 1.5 ha can be covered in a day.

(b) Manually Operated Pneumatic Sprayers

Since these sprayers work on a system of air compression, some air should be allowed to remain in the tank, which, therefore, should not be filled with spray fluid completely. They do not have agitators and hence are not useful for spraying materials, which settle down quickly.

Hand sprayers: The container for the spray fluid also acts as the pressure chamber. An air pump attached to the chamber projects inside. The inner end of the discharge pipe runs down to the bottom of the container and its outlet terminates in a nozzle. Attached to the pipe is a release device. The tank is filled to three-fourth and the pump is worked to force air into the space to build sufficient pressure upon the spray fluid. With the release of the release device the air pressure forces the liquid up the outlet and through the nozzle to emerge in the form of a fine continuous spray. These sprayers are used extensively in kitchen gardens, in glass houses and indoors against household insects.

Knapsack sprayers: They are adopted for spraying large quantities of liquid. They are similar to pneumatic hand sprayers in principle. A typical pneumatic knapsack sprayer comprises a tank for holding the spray liquid as well as compressed air, a vertical air pump with a handle, filling hole with a strainer spray lance with nozzle and release and shut off devices. The tank is fitted with a plastic skirt that provides a convenient rest with the back of the operator and has shoulder straps that allow it to be carried. The pump has to be worked to maintain a pressure of 2 to 4 kg/cm^2.

It is necessary that the containers in such sprayers should be made of robust material and be leak proof. Before each refilling the tank the pressure should be released slowly.

These sprayers are used in agricultural pests, and mosquito control operations.

Manually Operated Mist Blowers

The common flit gun or air atomiser is a small, handy simple appliance. It works on the principle of air blast breaking up the spray droplets and carrying them to the target. It can be of a simple compression cylinder, usually made of tin, with air pump. The pump is a flexible leather piston which, when moved up and down, allows air to pass into the compression side of the cylinder on the return stroke. Hence valves are not necessary. The outlet of the cylinder is opposed at 90° to another orifice in a tube leading out of the liquid container and thus is modified into a nozzle. The container is a simple can with a filling hole and is usually suspended beneath the outlet and of the cylinder. It may have a capacity ranging from a few millilitres to a litre. On the compression stroke the flow of air draws up the spray fluid from the tank and the opposition of the high velocity air and liquid streams results in atomisation into minute droplets of 15–50 microns. Continuous pumping is necessary though the spraying is not continuous. These appliances are useful for spot treatment in household spraying against bed bugs, mosquitoes and house flies and for treating individual plants.

Power Operated Hydraulic Sprayers

A power operated hydraulic sprayer generally consists of a petrol engine and a framework in addition to the other standard components of a sprayer; various types of booms with equidistantly fixed nozzles may be attached with these sprayers. These include the stretcher sprayers, wheel-barrow sprayers and traction sprayers.

Power Operated Pneumatic Sprayers

In this sprayer compressed air from a compressor, which is driven by a small engine, is forced into the liquid container. The capacity of the container is about 45 litres. An outlet from the container may bear lances or guns or a small boom with nozzles. Sprayers of this type with much larger tanks of 250 – 2000 litres capacity and more powerful compressors are mounted on a tractor. Such large size sprayers are useful for spraying over extensive areas of crops in the plains.

Low Volume Sprayers

In these sprayers the spray fluid is atomised with the help of an air stream at high velocity. The knapsack mist blower now much in use in India delivers 6.8 to 42.5 m^3 of air/min at a velocity of 200 to 420 kmph. The tank is made of thick polyethylene and has a capacity of 10 to 12 litres. The fuel tank capacity is 10 to 15 litres. The blower is light, 12-20 kg inclusive of accessories and is provided with 1.2 to 3.0 hp petrol engine. This sprayer fitted with suitable accessories can also be used for dusting; during dusting the air blast enters into the tank through a tube with several holes.

ULV Applicators

The pesticide, in ULV formulation, is used undiluted at a quantity less than 6 l/ha and usually at 0.5 to 2.0 l/ha for field crops. The droplet size varies from 30 – 150 microns. Such small droplets cannot be forcibly propelled over a distance and their distribution, therefore, depends on gravity and air movement.

With ULV application the job can be done quickly and in time. Also on the basis of active ingredient ULV formulations are cheaper than EC formulations; spray deposits from ULV formulations persist longer than that from emulsions. However, the major disadvantage with ULV application is the availability of special ULV formulations of pesticides; the qualities for such a formulation are low volatility, low phytotoxicity and high concentration.

The ULV application is made by mist blowers fitted with restrictor nozzle or air craft with special nozzles. With ground spraying equipment for ULV, spraying an area of 8 ha can be covered in a day against 3 ha in LV spray with power operated knapsack and 0.5 to 0.8 ha in high volume with manually operated sprayers.

◆ Chapter 96

Aircraft Application of Insecticides

THE FIRST practical use of an aircraft in insect control work was carried out in Ohio, USA, in 1921 when lead arsenate was dusted to control the sphinx *Ceratoma catalapae*. In India this method has been used in pest control since 1951. The Ministry of Food and Agriculture of the Government of India set up an aerial service. The Directorate of Plant Protection at New Delhi and private agencies cooperated by extending their service. In India aerial spray applications of concentrated chemicals at ultra low volume rates and without being diluted with water was employed in the control of mosquitoes and pests of paddy, wheat, sugarcane and cotton (Fig. 95.1). At present, aircraft application of insecticides is limited in India.

Aircraft application of insecticides have certain advantages. A large area could be speedily covered (200 to 800 hectares) in the application of spray or dust. If ultra low volume application is carried out the area covered by a plane will be twice or even three times more than that covered under ordinary methods. Accessibility is another advantage. Forest plantations, extensive crop fields etc. can be treated. Aerial spraying has an advantage over dusting because of the drift and possibilities of ready adjustment of dosage, rate and droplet size. However, dusting with fixed wing aircraft does not achieve coverage of lower leaf surfaces. Bad weather, mechanical troubles, etc. may delay the programme. While aircraft application has an advantage in that there is saving in manpower and machinery, it should also be mentioned that risks and accidents could not be ruled out.

▲ **Fig. 96.1** *Spraying insecticide on rice crop with helicopter*

There are obvious advantages in using a helicopter. It is easy to manoeuvre than a fixed wing aircraft. Navigational hazards like trees, wires, etc. do not form serious impediments: there is minimal drift of the pesticide; the pilots have better vision of the field of application; specialised landing or take off are not necessary; ferrying is quicker and the low altitude flight is helpful.

Appendix

LIST OF INSECTS INFESTING SHRUBS, PLANTS AND TREES IN INDIA (Including Storage Pests)

Common name	*Scientific name*	*Family*	*Order*
	CEREALS		
	***Avena sativa* (OATS)**		
Sugarcane pyrilla	*Pyrilla perpusilla* Wlk.	Lophopidae	Hemiptera
Greasy cutworm	*Agrotis ipsilon* (Hufn.)	Noctuidae	Lepidoptera
Cutworm	*Mythimna separata* (Wlk.)	Noctuidae	Lepidoptera
Army worm	*M. loreyi* (Dup.)	Noctuidae	Lepidoptera
	***Hordeum vulgare* (BARLEY)**		
Cow bug	*Tricentrus bicolor* Dist	Membracidae	Hemiptera
Plant lice	*Rhopalosiphum maidis* Fitch.	Aphididae	Hemiptera
Sugarcane pyrilla	*Pyrilla perpusilla* Wlk.	Lophopidae	Hemiptera
Black bug	*Scotinophara lurida* (Burm.)	Podopidae	Hemiptera
Greasy cutworm	*Agrotis ipsilon* (Hufn.)	Noctuidae	Lepidopetra
Shoot fly	*Atherigona naqvii* Steyskal	Anthomyiidae	Diptera
	***Oryza sativa* (PADDY OR RICE)**		
Spring tails	*Seira cinerea* Yosii	Entomobryidae	Collembolla
Surface grasshopper	*Chrotogonus trachypterus* Oliv.	Pyrgomorphidae	Orthoptera
	Acrida turrita (L.)	Acrididae	Orthoptera
	Acridium flavicorne Oliv.	Acrididae	Orthoptera

	Acrotylus humbertiana S.	Acrididae	Orthoptera
	Aiolopus affinis B.	Acrididae	Orthoptera
	A. tamulus F.	Acrididae	Orthoptera
Wingless grasshopper	*Colemania sphenariodes* (I. Bol.)	Acrididae	Orthoptera
	Heteroptermis respondens W.	Acrididae	Orthoptera
Rice grasshopper	*Hieroglyphus banian* (F.)	Acriddae	Orthoptera
	H. nigrorepletus (I. Bol.)	Acrididae	Orthoptera
	H. oryzivorus Carl.	Acrididae	Orthoptera
	Oedaleus infernalis De Sauss.	Acrididae	Orthoptera
	O. marmoratus Thunb.	Acrididae	Orthoptera
	Oxya bidentata Willernse	Acrididae	Orthoptera
	O. fuscovittata (Marschall)	Acrididae	Orthoptera
	(=*O. oryzivora* Will.)	Acrididae	Orthoptera
	O. hyla hyla Serville	Acrididae	Orthoptera
	(= *O. multidentata* Will.)	Acrididae	Orthoptera
Small rice grasshopper	*O. nitidula* Willemse	Acrididae	Orthoptera
	[=*O. velox* (Fb.)	Acrididae	Orthoptera
	=*O. vicina* Brunner	Acrididae	Orthoptera
	=*O. japonica japonica* (Thunb.)]	Acrididae	Orthoptera
	Pachytylus danicus L.	Acrididae	Orthoptera
	Parabolocratus porrectus Walker	Acrididae	Orthoptera
	Parahieroglyphus bilineatus Bol.	Acrididae	Orthoptera
Bombay locust	*Patanga succincta* (L.)	Acrididae	Orthoptera
	Pyrgomorpha conica O.		
Desert locust	*Schistocerca gregaria* (Forsk.)	Acrididae	Orthoptera
Javanese grasshopper	*Valanga nigricornis* Burm.	Acrididae	Orthoptera
Field cricket	*Brachytrupes portentosus* Licht.	Gryllidae	Orthoptera
	Gryllus conspersus Schaurn.	Gryllidae	Orthoptera
	Liogryllus bimaculatus (de Geer)	Gryllidae	Orthoptera
	Trigonidium cicindeloides (Serv.)	Gryllidae	Orthoptera
Mole cricket	*Gryllotalpa africana* (P.de Beauv)	Gryllotalpidae	Orthoptera
Termite	*Odontotermes obesus* Ramb.	Gryllotalpidae	Orthoptera
Frog hoppers	*Abidama rufia* Dist.	Cercopidae	Hemiptera
	A. productus Walker	Cercopidae	Hemiptera
	Callitettix versicolor (Fb.)	Cercopidae	Hemiptera
	Clovia punctata Walk.	Cercopidae	Hemiptera
	Cosmoscarta bispecularis White	Cercopidae	Hemiptera
	Poophilus costalis Walk.	Cercopidae	Hemiptera
	Athysanus indicus Dist.	Cicadellidae	Hemiptera
	A. fusconervosus Motsch.	Cicadellidae	Hemiptera
	Balclutha pararubrostriata Ramasubba Rao & Usha	Cicadellidae	Hemiptera
	Batracomorphus angustatus (Osborn)	Cicadellidae	Hemiptera
	Cicadula fascifrons Stal.	Cicadellidae	Hemiptera
	Cicadulina bipunctella Mats.	Cicadellidae	Hemiptera

White leafhopper	*Cofana spectra* (Dist).	Cicadellidae	Hemiptera
	Deltocephalus distinctus Motsch.	Cicadellidae	Hemiptera
Zig-zag striped leafhopper	*D. dorsalis* Motsch.	Cicadellidae	Hemiptera
	D. krameri Ramasubba Rao & Usha	Cicadellidae	Hemiptera
	D. veinatus Pruthi	Cicadellidae	Hemiptera
	Doratulina rubrolineata (Dist.)	Cicadellidae	Hemiptera
	Emposaca notata Melichar	Cicadellidae	Hemiptera
	Exitianus indicus (Distant)	Cicadellidae	Hemiptera
	Goniagnathus fumosus Distant	Cicadellidae	Hemiptera
	G. guttulinervis (Krischbaum)	Cicadellidae	Hemiptera
	Hecalus paraumballaensis Ramasubba Rao & Usha	Cicadellidae	Hemiptera
	H. prasinus Matsumura	Cicadellidae	Hemiptera
	Hishimonus phycitis (Distant)	Cicadellidae	Hemiptera
Green leafhopper	*Nephotettix nigropictus* (Stal.)	Cicadellidae	Hemiptera
Green leafhopper	*N. virescens* (Distant)	Cicadellidae	Hemiptera
	Nirvana pallida Melichar	Cicadellidae	Hemiptera
	N. suturalis Melichar	Cicadellidae	Hemiptera
Planthopper	*Oliarus caudatus* Walker	Cicadellidae	Hemiptera
	Selenocephalus virescens Dist.	Cicadellidae	Hemiptera
	Tettigella viridis (L.)	Cicadellidae	Hemiptera
	Tettigoniella albida Sign.	Cicadellidae	Hemiptera
	Thaia subrufa (Motsch.)	Cicadellidae	Hemiptera
	Thomsoniella albomaculata Dist.	Cicadellidae	Hemiptera
	Yasumateus mimicus (D.) (*= Kolla mimica)*	Cicadellidae	Hemiptera
	Zygina maculifrons (Motsch.)	Cicadellidae	Hemiptera
	Javesella pellucida (F.)	Delphacidae	Hemiptera
Brown planthopper	*Nilaparvata lugens* (Stal.)	Delphacidae	Hemiptera
	Peregrinus maidis (Ashm.)	Delphacidae	Hemiptera
	Perkinsiella sinensis Kirk.	Delphacidae	Hemiptera
	Sardia rostrata Melichar	Delphacidae	Hemiptera
	Sogata pusana Dist.	Delphacidae	Hemiptera
White-backed hopper	*Sogatella furcifera* (Horv.)	Delphacidae	Hemiptera
	Unkanodes sapporonus (Mats.)	Delphacidae	Hemiptera
	Proutista moesta (Westw.)	Derbidae	Hemiptera
	Eponisia guttula Mats.	Meenoplidae	Hemiptera
	Nisia atronervosa Leth.	Meenoplidae	Hemiptera
White striated planthopper	*N. nervosa* (Motsch)	Meenoplidae	Hemiptera
Sugarcane pyrilla	*Pyrilla perpusilla* Walker	Lophopidae	Hemiptera
Rusty root aphid	*Hysteroneura setariae* (Thomas)	Aphididae	Hemiptera
Leaf aphid	*Melanaphis vandergoot* R. & B.	Aphididae	Hemiptera
Rice root aphid	*Rhopalosiphum rufiabdominalis* (Sasaki)	Aphididae	Hemiptera
	Schizaphis graminum (Rond.)	Aphididae	Hemiptera

Ragi root aphid	*Tetraneura nigriabdominalis* (Sasaki)	Aphididae	Hemiptera
	T. radicicola	Aphididae	Hemiptera
Whitefly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	Hemiptera
	Vasdavidius indicus (David & Sub.)	Aleyrodidae	Hemiptera
Rice mealy bug	*Heterococcus rehi* (Lindinger)	Pseudococcidae	Hemiptera
Lace-wing bug	*Bako malayanus* (Drake)	Tingidae	Hemiptera
Sugarcane black bug	*Cavelerius sweeti* Slater & Mugomoto	Lygaeidae	Hemiptera
Grain bug	*Horridipanura nietneri* Dohrn.	Lygaeidae	Hemiptera
	Gerris nitida Mayr.	Gerridae	Hemiptera
Paddy bug, Rice bug	*Leptocorsia acuta* (Thumb.)	Alydidae	Hemiptera
	L. oratorio (F.)	Alydidae	Hemiptera
	Cletus bipunctatus Westw.	Coreidae	Hemiptera
	Cletus signatus (Walk.)	Coreidae	Hemiptera
	C. trigonus Thumb.	Coreidae	Hemiptera
	Leptoglossus australis (F.)	Coreidae	Hemiptera
	Pendulinus nicobarensis Mayr.	Coreidae	Hemiptera
	Riptortus fascus F.	Coreidae	Hemiptera
Malayan black rice bug	*Scotinophara coarctata (F.)*	Podopidae	Hemiptera
Black bug	*S. lurida (*Burm.)	Podopidae	Hemiptera
	Audinetis spinidens Guer.	Pentatomidae	Hemiptera
	Dolycoris indicus Stal.	Pentatomidae	Hemiptera
	Eysarcoris guttiger Thunb.	Pentatomidae	Hemiptera
Earhead shield bug	*Menida histrio* (F.)	Pentatomidae	Hemiptera
Green rice bug	*Nezara viridula* (L.)	Pentatomidae	Hemiptera
	Storthecoris nigriceps Horv.	Pentatomidae	Hemiptera
Striped shield bug	*Tetroda histeroides* (F.)	Pentatomidae	Hemiptera
Stored rice psocid	*Liposcellis* sp.	Liposcellidae	Psocoptera
Leaf sheath thrips	*Anaphothrips sudanensis* (Trybom)	Thripidae	Thysanoptera
Rice thrips	*Stenchaetothrips biformis* (Bagnall)	Thripidae	Thysanoptera
Inflorescence thrips	*Haplothrips ganglbaueri* Schm.	Phlaeothripidae	Thysanoptera
	Brachmia arotraa Meyr.	Gelechiidae	Lepidoptera
Angoumois grain moth	*Sitotroga cerealella* Oliv.	Gelechiidae	Lepidoptera
Slug caterpillar	*Parasa bicolor* (Walk.)	Limacodiidae	Lepidoptera
	Niphadoses gilviberbis (Zeil.)	Galleriidae	Lepidoptera
Rice meal moth	*Corcyra cephalonica* St.	Galleriidae	Lepidoptera
Root caterpillar	*Ancylolomia chrysographella (K*oll.)	Pyralidae	Lepidoptera
	Bradina admixtalis (Walk.)	Pyralidae	Lepidoptera
Fig moth	*Cadra cautella* (Walk.)	Pyralidae	Lepidoptera
Gold-fringed borer	*Chilo auricilius Dudg.*	Pyralidae	Lepidoptera
	C. infuscatellus (Snellen)	Pyralidae	Lepidoptera
Sorghum stemborer	*C. partellus* (Swinhoe)	Pyralidae	Lepidoptera
Dark-headed striped borer	*C. polychrysus* (Meyr.)	Pyralidae	Lepidoptera
Sugarcane stemborer	*Chilo sacchariphagus indicus* (Kapur)	Pyralidae	Lepidoptera
Pale-headed striped borer	*C. suppressalis* (Walk.)	Pyralidae	Lepidoptera

Leaf roller	*Cnaphalocrocis eryxalis* Walk.	Pyralidae	Lepidoptera
Leaf roller	*C. medinalis* (Guen.)	Pyralidae	Lepidoptera
Leaf folder	*C. patnalis* Bradley	Pyralidae	Lepidoptera
Leaf folder	*C. ruralis*	Pyralidae	Lepidoptera
	C. suspicalis W.	Pyralidae	Lepidoptera
	Ostrinia nubilalis (Hubn.)	Pyralidae	Lepidoptera
	Paraponyx fluctuosalis Zell.	Pyralidae	Lepidoptera
Rice caseworm	*Paraponyx stagnalis*	Pyralidae	Lepidoptera
	Pleuroptya (= Sylepta) balteata (F.)	Pyralidae	Lepidoptera
	Herpetogramma phaeopteralis Guen.	Pyralidae	Lepidoptera
Ragi white borer	*Saluria inficita* Walk.	Pyralidae	Lepidoptera
Yellow stem borer	*Scirpophaga incertulas (Walk.)*	Pyralidae	Lepidoptera
Leaf folder	*Susumia exigua* (Butl.)	Pyralidae	Lepidoptera
White stem borer or	*Scirpophaga innotata* (Walk.)	Pyralidae	Lepidoptera
Sugarcane top borer	*Scirpophaga excerptalis*	Pyralidae	Lepidoptera
Hairy caterpillar	*Metanastria hyrtaca* C.	Lasiocampidae	Lepidoptera
	Nisaga simplex Walk.	Eupterotidae	Lepidoptera
	Melanitis determinata (Bttr.)	Nymphalidae	Lepidoptera
Horned caterpillar	*M. leda ismene* C.	Nymphalidae	Lepidoptera
	Mycalesis perseus F.	Nymphalidae	Lepidoptera
	Orsotriaena meda F.	Nymphalidae	Lepidoptera
	Procis almana (L.)	Nymphalidae	Lepidoptera
	Catopsilia pomona form *crocale* F.	Pieridae	Lepidoptera
	Eurema hecabe (Linn.)	Pieridae	Lepidoptera
	Ampittia dioscorides (F.)	Hesperiidae	Lepidoptera
	Borobo cinnara	Hesperiidae	Lepidoptera
	Parnara guttatus guttatus B. & G.	Hesperiidae	Lepidoptera
Rice skipper	*Pelopidas mathias mathias* (Fb.)	Hesperiidae	Lepidoptera
Sugarcane skipper	*Telicota augias* (L.)	Hesperiidae	Lepidoptera
Woolly bear	*Amsacta lactinea* (Cr.)	Arctiidae	Lepidoptera
	Amsacta lineola (Fb.)	Arctiidae	Lepidoptera
	Creatonotus gangis (L.)	Arctiidae	Lepidoptera
	Dinara combusta (Walk.)	Notodonitidae	Lepidoptera
	Agrotis ipsilon (Hufn.)	Noctuidae	Lepidoptera
	A. segetum (Schiff.)	Noctuidae	Lepidoptera
	Chrysodeixis chalcites Esp.	Noctuidae	Lepidoptera
Gram caterpillar	*Helicoverpa armigera* Hb.	Noctuidae	Lepidoptera
	Mocis frugalis (F.)	Noctuidae	Lepidoptera
	Mythimna albistigma (M.)	Noctuidae	Lepidoptera
	M. loreyi (Dup.)	Noctuidae	Lepidoptera
Rice army worm	*M. separata* (Walk.)	Noctuidae	Lepidoptera
	M. venalba (M.)	Noctuidae	Lepidoptera
	Naranga aenescens M.	Noctuidae	Lepidoptera
	N. diffusa (Walk.)	Noctuidae	Lepidoptera
	Plusia lectula Walk.	Noctuidae	Lepidoptera
Purple stem-borer	*Sesamia inferens* (Walk.)	Noctuidae	Lepidoptera
	S. uniformis Dudg.	Noctuidae	Lepidoptera

	Spodoptera exempta (Walk.)	Noctuidae	Lepidoptera
	S. exigua (Hubn.)	Noctuidae	Lepidoptera
Paddy army worm	*S. frugiperda* (S. & A.)	Noctuidae	Lepidoptera
Tobacco cutworm	*S. litura* (F.)	Noctuidae	Lepidoptera
Swarming caterpillar	*S. mauritia* (Boisd.)	Noctuidae	Lepidoptera
	Xanthodes intersepta Gn.	Noctuidae	Lepidoptera
	Xestia c-nigrum (L.)	Noctuidae	Lepidoptera
Tussock caterpillar	*Euproctis subnotata* Walk	Lymantriidae	Lepidoptera
	E. varians Walk.	Lymantriidae	Lepidoptera
	E. virgo (Swinhoe)	Lymantriidae	Lepidoptera
	E. virguncula Walk.	Lymantriidae	Lepidoptera
	E. xanthorrhoea (Koll.)	Lymantriidae	Lepidoptera
	Laelia suffusa Walker	Lymantriidae	Lepidoptera
Rice hairy caterpillar	*Psalis pennatula* (F.)	Lymantriidae	Lepidoptera
Rice gallmidge or	*Orseolia oryzae* (Wood-Mason)	Cecidomyiidae	Diptera
Rice fly	*Hydrellia philippina* Ferino	Ephydridae	Diptera
	H. sasakii Yuasa and Isitani	Ephydridae	Diptera
Seedling root fly	*Notiphila dorsopunctata* Wied	Ephydridae	Diptera
Rice stem fly	*Atherigona oryzae* Mall.	Anthomyiidae	Diptera
Sorghum shoot fly	*A. varia soccata* Rond.	Anthomyiidae	Diptera
Fruit fly	*Oscinella frit* L.	Chloropidae	Diptera
	Conosia irrorata Wied.	Tipulidae	Diptera
Leaf miner	*Pseudonapomyza atra* (Meig.)	Agromyzidae	Diptera
	Euetheola rugiceps (Lee.)	Dynastidae	Coleoptera
	Heteronychus lioderes Redt.	Dynastidae	Coleoptera
Bhatula beetle	*H. poropygus* Bates	Dynastidae	Coleoptera
	Phyllognathus dionysius (F.)	Dynastidae	Coleoptera
	Xylotrupes gideon (Linn.)	Dynastidae	Coleoptera
	Oxycetonia albopunctata F.	Cetoniidae	Coleoptera
	Holotrichia longipennis Blanch.	Melolonthidae	Coleoptera
	H. seticollis M.	Melolonthidae	Coleoptera
	Adoretus caliginosus Burm.	Rutelidae	Coleoptera
	Anomala dimidiata (Hope)	Rutelidae	Coleoptera
	A. dimidiata var. *barbata* Burm.	Rutelidae	Coleoptera
	A. polita (Blanch)	Rutelidae	Coleoptera
	A. rugosa Arrow	Rutelidae	Coleoptera
	A. varians (Oliv.)	Rutelidae	Coleoptera
	Popillia cupricollis Hope	Rutelidae	Coleoptera
	Ora picta (F.)	Dascillidae	Coleoptera
Pollen beetle	*Alesia discolor* F.	Coccinellidae	Coleoptera
	A. univittata Hope	Coccinellidae	Coleoptera
Khapra beetle	*Trogoderma granarium* (Everts.)	Dermestidae	Coleoptera
Lesser grain borer	*Rhyzopertha dominica* (Fabr.)	Bostrychidae	Coleoptera
"Cadella" beetle	*Tenebroides mauritanicus* (Linn.)	Trogositidae	Coleoptera
Flat grain beetle	*Laemophloeus minutus* Oliv.	Cucujidae	Coleoptera
Saw toothed beetle	*Oryzaephilus surinamensis* Linn.	Silvanidae	Coleoptera
Lesser meal worm	*Alphitobius piceous* Oliv.	Tenebrionidae	Coleoptera

Root grub	*Arthrodeis* sp.	Tenebrionidae	Coleoptera
Flour beetle	*Latheticus oryzae* W.	Tenebrionidae	Coleoptera
Yellow meal worm	*Tenebrio monitor Linn.*	Tenebrionidae	Coleoptera
Red flour beetle	*Tribolium castaneum* Hebst.	Tenebrionidae	Coleoptera
	Cyaneolytta actaeon (Lap.)	Meloidae	Coleoptera
	Cylindrothorax tenuicollis Pall.	Meloidae	Coleoptera
	Epicauta hirticornis Haag.	Meloidae	Coleoptera
	Lytta ruficollis O.	Meloidae	Coleoptera
Blister beetle	*Mylabris phalerata* Palls.	Meloidae	Coleoptera
	Psalydolytta rouxi (Lap.)	Meloidae	Coleoptera
Rice hispa	*Dicladispa armigera* (Oliv.)	Hispidae	Coleoptera
	Hispa stygia (Chap.)	Hispidae	Coleoptera
	Rhadinosa lebongensis Maulik.	Hispidae	Coleoptera
	Donacia aeraria Baly.	Donaciidae	Coleoptera
	Oides affinis Jac.	Galerucidae	Coleoptera
Flea beetle	*Chaetocnema basalis* Baly.	Alticidae	Coleoptera
	C. coccipennis B.	Alticidae	Coleoptera
	Ligyrus rugiceps Lee.	Alticidae	Coleoptera
	Caryedon serratus (Olivier)	Bruchidae	Coleoptera
	Athesapeuta oryzae Mshll.	Curculionidae	Coleoptera
Root weevil	*Cyrtozemta* sp.	Curculionidae	Coleoptera
	Echinocnemus oryzae Mshll.	Curculionidae	Coleoptera
	Hydronomidius molitor Faust.	Curculionidae	Coleoptera
	Myllocerus blandus Faust.	Curculionidae	Coleoptera
	Myllocerus dentifer (F.)	Curculionidae	Coleoptera
	M. discolor (F.)	Curculionidae	Coleoptera
	Phytoscaphus triangularis OI.	Curculionidae	Coleoptera
Rice weevil	*Sitophilus oryzae* Linn.	Curculionidae	Coleoptera
	Tanymecus hispidus Mshll.	Curculionidae	Coleoptera
	T. indicus Fst.	Curculionidae	Coleoptera
	Xanthochelus faunus (Ol.)	Curculionidae	Coleoptera

Triticum vulgare (WHEAT)

Surface grasshopper	*Chrotogonus brachypterus* (Bl.)	Pyrgomorphidae	Orthoptera
Small Rice grasshopper	*Oxya nitidula* Willemse	Acrididae	Orthoptera
Bombay locust	*Patanga succincta* (Linn.)	Acrididae	Orthoptera
Termites	*Microtermes obesi* Holm.	Termitidae	Isoptera
	Odontotermes obesus Ramb.	Termitidae	Isoptera
Leafhopper	*Empoasca nagpurensis* Dist.	Cicadellidae	Hemiptera
	Empoascanara maculifrons (Motsch.)	Cicadellidae	Hemiptera
Pea aphid	*Acrythosiphum pisum* Harris	Aphididae	Hemiptera
Indian grain aphid	*Macrosiphum (Sitobion) miscanthi* Tak	Aphididae	Hemiptera
	Melanaphis sacchari (Zehnt.)	Aphididae	Hemiptera
	Myzus persicae Suiz.	Aphididae	Hemiptera
Leaf whorl aphid	*Rhopalosiphum maidis* Fitsch.	Aphididae	Hemiptera

Oat aphid	*R. padi* (Linnaeus)	Aphididae	Hemiptera
	Schizaphis graminum Rond.	Aphididae	Hemiptera
Sugarcane pyrilla	*Pyrilla perpusilla* Walker	Lophopidae	Hemiptera
	Riptortus pedestris F.	Coreidae	Hemiptera
	Agonoscelis nubila Fb.	Pentatomidae	Hemiptera
	Dolycoris indicus Stal.	Pentatomidae	Hemiptera
	Euridema pulchrus West.	Pentatomidae	Hemiptera
	Menida histrio Fb.	Pentatomidae	Hemiptera
	Nezara hilaris Say	Pentatomidae	Hemiptera
	N. viridula Linn.	Pentatomidae	Hemiptera
Wheat thrips	*Anaphothrips sudanensis* Trybom	Thripidae	Thysanoptera
Leaf roller	*Herpetogramma phaeopteralis* (Guen.)	Pyralidae	Lepidoptera
Cutworm or army worm	*Agrotis biconica* Koll.	Noctuidae	Lepidoptera
	A. flammatra R.	Noctuidae	Lepidoptera
	A. ipsilon (Hufn.)	Noctuidae	Lepidoptera
	A. spinifera (Hubner)	Noctuidae	Lepidoptera
	Mythimna separata (Walk.)	Noctuidae	Lepidoptera
	M. loreyi (Dup.)	Noctuidae	Lepidoptera
Climbing cutworm	*Rhyacia herculea* Corti & Dr.	Noctuidae	Lepidoptera
Ragi pink borer	*Sesamia inferens* (Walk.)	Noctuidae	Lepidoptera
Tobacco cutworm	*Spodoptera litura* (F.)	Noctuidae	Lepidoptera
Shootfly	*Atherigona simplex* (Thomson)	Anthomyiidae	Diptera
	A. naqvii Steyskal	Anthomyiidae	Diptera
	A. punctata Karl.	Anthomyiidae	Diptera
Ant	*Holcomyrmex scabriceps* Mayr.	Formicidae	Hymenoptera
Flea beetle	*Chaetocnema basalis* Baly.	Alticidae	Coleoptera
	Phyllotreta chotanica Duv.	Alticidae	Coleoptera
	Myllocerus blandus Faust	Curculionidae	Coleoptera
	M. discolor F.	Curculionidae	Coleoptera
	Sitones crinitus Oliv.	Curculionidae	Coleoptera
Rice weevil	*Sitophilus oryzae* L.	Curculionidae	Coleoptera
	Tanymecus indicus Fst.	Curculionidae	Coleoptera

MILLET CROPS

Echinochloa colona (BARNYARD MILLET)

Rice bug	*Leptocorsia acuta* (Thunb.)	Alydidae	Hemiptera
Corn lantern fly	*Peregrinus maidis* Ashm.	Delphacidae	Hemiptera
Rice mealy bug	*Heterococcus rehi* (Lind.)	Pseudococcidae	Hemiptera
Stem fly	*Atherigona falcata* Thomson	Anthomyiidae	Diptera
	A. pulla (Wiedemann)	Anthomyiidae	Diptera

Eleusine coracana (FINGER MILLET)

Grasshopper	*Acrida exaltata* Walk.	Acrididae	Orthoptera
	Catantops pinguisinnotabilis Walk.	Acrididae	Orthoptera
	Hieroglyphus banian Fab.	Acrididae	Orthoptera
Wingless grasshopper	*Neorthacris simulans* B.	Acrididae	Orthoptera

Earwig	*Elaunon bipartitus* Kirby	Forficulidae	Dermaptera
Thrips	*Anaphothrips sudanensis* Trybom	Thripidae	Thysanoptera
	Caliothrips indicus (Bagnall)	Thripidae	Thysanoptera
Rice mealy bug	*Heterococcus rehi* (Lindinger)	Pseudococcidae	Hemiptera
Rusty plum aphid	*Hysteroneura setariae* (Thomas)	Aphididae	Hemiptera
Creamy aphid	*Melanaphis sacchari* (Zehnt.)	Aphididae	Hemiptera
Yellow plant lice	*Rhopalosiphum maidis* Fitch.	Aphididae	Hemiptera
	R. rufiabdominalis (Sasaki)	Aphididae	Hemiptera
Green aphid	*Schizaphis graminum* R.	Aphididae	Hemiptera
Ragi root aphid	*Tetraneura nigriabdominalis* (Sasaki)	Aphididae	Hemiptera
Leaf hopper	*Cicadulina bipunctella* (Matsumara)	Cicadellidae	Hemiptera
	C. chinai Ghauri	Cicadellidae	Hemiptera
	Psammotettix striatus L.	Cicadellidae	Hemiptera
Earhead bug	*Calocoris angustatus* Leth.	Miridae	Hemiptera
Rice bug	*Leptocorisa acute* (Thunb.)	Alydidae	Hemiptera
	Dolycoris indicus S.	Pentatomidae	Hemipetra
	Nezara viridula Linn.	Pentatomidae	Hemipetra
Painted bug	*Bagrada cruciferarum* Kirkaldy	Pentatomidae	Hemiptera
Angoumois grain moth	*Sitotroga cerealella* (Oliv.)	Gelechiidae	Lepidoptera
	Stathmopoda theoris Meyr.	Heliodinidae	Lepidoptera
Slug caterpillar	*Thosea aperiens* Wlk.	Limacodiidae	Lepidoptera
Sorghum stemborer	*Chilo partellus* (Swinhoe)	Pyralidae	Lepidoptera
White borer	*Saluria inficita* W.	Pyralidae	Lepidoptera
Earhead web worm	*Cryptoblabes angustipennella* Hmpsn.	Pyralidae	Lepidoptera
Rice leafroller	*Cnaphalocrocis medinalis* Guen.	Pyralidae	Lepidoptera
Rice skipper	*Pelopidas mathias mathias* Fb.	Hesperiidae	Lepidoptera
Red hairy caterpillar	*Amsacta albistriga* M.	Arctiidae	Lepidoptera
Black hairy caterpillar	*Amsacta (= Estigmene) lactinea* (Cr.)	Arctiidae	Lepidoptera
Red hairy caterpillar	*A. moorei* Butl.	Arctiidae	Lepidoptera
Bihar hairy caterpillar	*Spilarctia obliqua* (Wlk.)	Arctiidae	Lepidoptera
	Anticarsia irrorata F.	Noctuidae	Lepidoptera
	Azazia rubricans B.	Noctuidae	Lepidoptera
Earhead caterpillar	*Eublemma silicula* Swinh.	Noctuidae	Lepidoptera
Gram pod borer	*Helicoverpa armigera* Hb.	Noctuidae	Lepidoptera
Cutworm	*Mythimna separata* (Wlk.)	Noctuidae	Lepidoptera
Leaf semilooper	*Moscis frugalis* (F.)	Noctuidae	Lepidoptera
Pink borer	*Sesamia inferens* Wlk.	Noctuidae	Lepidoptera
Sorghum stalk caterpillar	*Simplicia robustalis* G.	Noctuidae	Lepidoptera
Cutworm	*Spodoptera exigua* (Hubn.)	Noctuidae	Lepidoptera
Looper caterpillar	*Hyposidra talaca* H.	Geometridae	Lepidoptera
Stemfly or shootfly	*Atherigona varia soccata* Rond.	Anthomyiidae	Diptera
White grub	*Holotrichia consanguinea* Bl.	Melolonthidae	Coleoptera
	H. seticollis M.	Melolonthidae	Coleoptera
Root grub	*Anomala dimidiata* var. *barbata* Burn.	Rutelidae	Coleoptera

Defoliator	*Mimela fulgidivittata* Blanch	Rutelidae	Coleoptera
Earhead beetle	*Popillia cupricollis* Hope	Rutelidae	Coleoptera
Leaf feeder	*Xylotrupes gideon* Linn.	Dynastidae	Coleoptera
Soldier beetle	*Cordylocera livida* Hope	Cantharidae	Coleoptera
Click beetle	*Dicronychus* sp.	Elateridae	Coleoptera
Flea beetle	*Chaeonema pusaensis* M.	Alticidae	Coleoptera
Leaf beetle	*Lema downsei* Baly.	Galeuricidae	Coleoptera
	Monolepta signata Ol.	Galeuricidae	Coleoptera
Leaf weevil	*Myllocerus discolor* F.	Curculionidae	Coleoptera
	M. maculosus Desbr.	Curculionidae	Coleoptera
	M. viridanus F.	Curculionidae	Coleoptera

Panicum miliaceum (COMMON MILLET)

Leaf roller	*Herpetogramma phaeopteralis* (Guen.)	Pyralidae	Lepidoptera
Stem fly	*Atherigona miliaceae* Malloch	Anthomyiidae	Diptera
Flea beetle	*Chaetocnema pusaensis* M.	Alticidae	Coleoptera

Panicum miliare (LITTLE MILLET)

Rice bug	*Leptocorisa acuta* (Thunb.)	Alydidae	Hemiptera
Cut worm	*Mythimna separata* (Walk.)	Noctuidae	Lepidoptera
Stem fly	*Atherigona pulla* (Wiedemann)	Anthomyiidae	Diptera
	A. miliaceae Malloch	Anthomyiidae	Diptera
Leaf beetle	*Myllocerus dentifer* F.	Curculionidae	Coleoptera

Paspalum scrobiculatum ('KODI' MILLET)

Corn lantern fly	*Peregrinus maidis* Ashm.	Delphacidae	Hemiptera
Rice mealy bug	*Heterococcus rehi* (Lind.)	Pseudococcidae	Hemiptera
Rice skipper	*Pelopidas mathias mathias* Fb.	Hesperiidae	Lepidoptera
Cutworm	*Mythimna separata* (Wlk.)	Noctuidae	Lepidoptera
Stem fly	*Atherigona simplex* (Thomson)	Anthomyiidae	Diptera
	A. oryzae Malloch	Anthomyiidae	Diptera
	A. pulla (Wiedemann)	Anthomyiidae	Diptera
Gall midge	*Itonida paspalumi* Mani	Cecidomyiidae	Diptera
	Parallelodiplosis paspali Felt	Cecidomyiidae	Diptera

Pennisetum typhoideum (BULRUSH MILLET)

Wingless grasshopper	*Colemania sphenarioides* Bol.	Acrididae	Orthoptera
	Hieroglyphus nigrorepletus (Bol.)	Acrididae	Orthoptera
Wingless grasshopper	*Neorthacris simulans* Bol.	Acrididae	Orthoptera
Bombay locust	*Patanaga succinacta* (Linn.)	Acrididae	Orthoptera
Sugarcane pyrilla	*Pyrilla perpusilla* Wlk.	Lophopidae	Hemiptera
Corn lantern fly	*Peregrinus maidis* Ashm.	Delphacidae	Hemiptera
Earhead bug	*Calocoris angustatus* Leth.	Miridae	Hemiptera
Rice bug	*Leptocorisa acuta* (Thunb.)	Alydidae	Hemiptera
Seed bug	*Elasmolomus sordidus* F.	Lygaeidae	Hemiptera

Root bug	*Stibaropus minor* B	Cydnidae	Hemiptera
	Dolycoris indicus S	Pentatomidae	Hemiptera
	Eysarcoris guttiger Thunb.	Pentatomidae	Hemiptera
	Nezara viridula Linn.	Pentatomidae	Hemiptera
Leaf thrips	*Anaphothrips sudanensis* Trybom	Thripidae	Thysanoptera
	Florithrips traegardhi (Trybom)	Thripidae	Thysanoptera
	Thrips hawaiiensis (Morgan)	Thripidae	Thysanoptera
	Haplothrips gowdeyi (Franklin)	Phlaeothripidae	Thysanoptera
Fig moth	*Cadra cautella* (Wlk.)	Pyralidae	Lepidoptera
Sorghum stem borer	*Chilo partellus* (Swinhoe)	Pyralidae	Lepidoptera
Leaf roller	*Cnaphalocrocis trapezalis* Guen.	Pyralidae	Lepidoptera
Root borer	*Emmalocera depressella* Swinh.	Pyralidae	Lepidoptera
Angoumois grain moth	*Sitotroga cerealella* (Oliv.)	Gelechiidae	Lepidoptera
Earhead caterpillar	*Pyroderces simplex* Wlsm.	Cosmopterygidae	Lepidoptera
Red hairy caterpillar	*Amsacta albistriga* M.	Arctiidae	Lepidoptera
Black hairy caterpillar	*A. lactinea* (Cr.)	Arctiidae	Lepidoptera
	A. moorei Butl.	Arctiidae	Lepidoptera
Bihar hairy caterpillar	*Spilarctia obliqua* (Wlk.)	Arctiidae	Lepidoptera
Earhead semilooper	*Eublemma silicula* Swinhoe	Noctuidae	Lepidoptera
Pink stem borer	*Sesamia inferens* Wlk.	Noctuidae	Lepidoptera
Stem fly	*Atherigona approximata* Malloch.	Anthomyiidae	Diptera
Gall midge	*Geromyia penniseti*	Cecidomyiidae	Diptera
	Itonida seminis Felt.	Cecidomyiidae	Diptera
Root grub	*Arthrodeis* sp.	Tenebrionidae	Coleoptera
White grub	*Holotrichia consanguinea* Blanch.	Melolonthidae	Coleoptera
	H. insularis Brenske	Melolonthidae	Coleoptera
	Rhinyptia laeviceps Arrow	Scarabaeidae	Coleoptera
Chafer beetle	*Chiloloba acuta* W.	Cetoniidae	Coleoptera
	Spilophorus sp.	Cetoniidae	Coleoptera
Earhead blister beetle	*Cylindrothorax tenuicollis* P.	Meloidae	Coleoptera
	Gnathospastoides rouxi C.	Meloidae	Coleoptera
Blister beetle	*Mylabris pustulata* Thunb.	Meloidae	Coleoptera
Leaf beetle	*Lema downsei* B.	Galerucidae	Coleoptera
	Myllocerus maculosus Desbr.	Curculionidae	Coleoptera
	M. viridanus F.	Curculionidae	Coleoptera

Setaria italica (ITALIAN MILLET)

Wingless grasshopper	*Colemania sphenarioides* Bol.	Acrididae	Orthoptera
Corn lantern fly	*Peregrinus maidis* Ashm.	Delphacidae	Hemiptera
Rice bug	*Leptocorisa acuta* (Thunb.)	Alydidae	Hemiptera
Paddy leafhopper	*Nephotettix nigropictus* (Stal.)	Cicadellidae	Hemiptera
Rice black bug	*Scotinophara lurida* (Burm.)	Podopidae	Hemiptera
Stem borer	*Chilo infuscatellus* (Snell.)	Pyralidae	Lepidoptera
White borer	*Saluria infictia* W.	Pyralidae	Lepidoptera
	Anticarsia irrorata F.	Noctuidae	Lepidoptera
	Azazia rubricans B.	Noctuidae	Lepidoptera

Cutworm	*Mythimna separata* (Walk.)	Noctuidae	Lepidoptera
Stem fly	*Atherigona pulla* (Wiedemann)	Anthomyiidae	Diptera
	A. atripalpis Malloch	Anthomyiidae	Diptera
Leaf beetle	*Myllocerus dentifer* F.	Curculionidae	Coleoptera
	M. transmarinus M.	Curculionidae	Coleoptera
Stem borer	*Anadastus parvulus* W.	Languriidae	Coleoptera

Sorghum vulgare **(SORGHUM)**

Surface grasshopper	*Chrotogonus saussurei* Bol.	Pyrgomorphidae	Orthoptera
Wingless grasshopper	*Colemania sphenarioides* Bol.	Acrididae	Orthoptera
	Hieroglyphus nigrorepletus Bol.	Acrididae	Orthoptera
Small rice grasshopper	*Oxya nitidula* Willemse	Acrididae	Orthoptera
Bombay locust	*Patanga succincta* (Linn.)	Acrididae	Orthoptera
Groundnut earwig	*Euborellia annulipes* Lucas	Forficulidae	Dermaptera
Sugarcane pyrilla	*Pyrilla perpusilla* Wlk.	Lophopidae	Hemiptera
Frog hopper	*Ptyelus sexvittatus* Walker	Cercopidae	Hemiptera
	Leptocentrus obliquus W.	Membracidae	Hemiptera
Tree hopper	*Tricentrus bicolor* Distant	Membracidae	Hemiptera
The corn lanternfly	*Peregrinus maidis* (Ashm.)	Delphacidae	Hemiptera
	Proutista moesta (Westw.)	Derbidae	Hemiptera
Sugarcane aleyrodid	*Neomaskellia bergii* Sign,	Aleyrodidae	Hemiptera
Tobacco whitefly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	Hemiptera
Root aphid	*Geoica lucifuga* (Zehnt.)	Aphididae	Hemiptera
Rusty plum aphid	*Hysteroneura setariae* (Thomas)	Aphididae	Hemiptera
Creamy aphid	*Melanaphis sacchari* (Zehhnt.)	Aphididae	Hemiptera
Yellow plant lice	*Rhopalosiphum maidis* Fitch.	Aphididae	Hemiptera
Ragi root aphid	*Tetraneura nigriabdominalis* (Sasaki)	Aphididae	Hemiptera
	Chorizococcus sorghi Williams	Pseudococcidae	Hemiptera
Rice mealy bug	*Heterococcus rehi* (Lindinger)	Pseudococcidae	Hemiptera
Sugarcane root mealy bug	*Saccharioccus sacchari* Ckll.	Pseudococcidae	Hemiptera
	Trionymus ceres Williams	Pseudococcidae	Hemiptera
Earhead bug	*Calocoris angustatus* Leth.	Miridae	Hemiptera
	Creontiades pallidus	Miridae	Hemiptera
	Campylomma livida Reuter	Miridae	Hemiptera
	Eurystylus velleveyei	Miridae	Hemiptera
	Megacaelum stramineum W.	Miridae	Hemiptera
	Ragmus flavomaculatus Ballard	Miridae	Hemiptera
	R. morosus Ballard	Miridae	Hemiptera
	Spilostethus hospes (F.)	Lygaeidae	Hemiptera
	S. militaris (F.)	Lygaeidae	Hemiptera
	S. pandurus (Scop.)	Lygaeidae	Hemiptera
	Horridipanura nietneri Dohrn.	Lygaeidae	Hemiptera
Grain bug	*Gerris nitida* Mayr.	Gerridae	Hemiptera
Rice bug	*Leptocorisa acuta* (Thumb)	Alydidae	Hemiptera
Root bug	*Stibaropus minor* Fb.	Cydnidae	Hemiptera
	Agonoscelis nubila F.	Pentatomidae	Hemiptera

	Dolycoris indicus S.	Pentatomidae	Hemiptera
	Menida histrio F.	Pentatomidae	Hemiptera
	Nezara viridula L.	Pentatomidae	Hemiptera
	Piezodorus ruburofasciatus F.	Pentatomidae	Hemiptera
	Anaphothrips sudanensis Trybom	Thripidae	Thysanoptera
	Caliothrips indicus (Bagnall)	Thripidae	Thysanoptera
	Sorghothrips jonnaphilus (Ramk.)	Thripidae	Thysanoptera
	Florithrips traegardhi (Trybom)	Thripidae	Thysanoptera
	Haplothrips ganglbaurei Schmutz	Phlaeothipidae	Thysanoptera
	Xylaplothrips pellucidus Anan.	Phlaeothripidae	Thysanoptera
Angoumois grain moth	*Sitotroga ceralella* (Olive.)	Gelechiidae	Lepidoptera
Earhead caterpillar	*Anatrachyntis simplex* Wlsm.	Cosmopterygidae	Lepidoptera
	Stathmopoda theoris Meyr.	Heliodinidae	Lepidoptera
Slug caterpillar	*Thosea aperiens* Wlk.	Limacodiidae	Lepidoptera
Gurdaspur borer	*Bissetia steniella* Hmpsn.	Pyralidae	Lepidoptera
Rice meal moth	*Corcyra cephalonica* St.	Pyralidae	Lepidoptera
Gold-fringed borer	*Chilo auricilius* (Dudgeon)	Pyralidae	Lepidoptera
Sorghum stemborer	*C. partellus* (Sinhoe)	Pyralidae	Lepidoptera
	C. sacchariphagus indicus (Kapur)	Pyralidae	Lepidoptera
Leaf roller	*Cnaphalocrocis suspicalis* W.	Pyralidae	Lepidoptera
Leaf roller	*C. trapezalis* Guen.	Pyralidae	Lepidoptera
Castor capsule borer	*Conogethes punctiferalis* Guen.	Pyralidae	Lepidoptera
Earhead web worm	*Cryptoblabes angustipennella* Hmpsn.	Pyralidae	Lepidoptera
	C. gnidiella Miller	Pyralidae	Lepidoptera
	Ectomyelois sp.	Pyralidae	Lepidoptera
Root Borer	*Emmalocera depresella* Swinh.	Pyralidae	Lepidoptera
Stubble borer	*Maliarpha separatella* Ragonot	Pyralidae	Lepidoptera
	Stenachroia elongella Hmpsn.	Pyralidae	Lepidoptera
Earhead caterpillar	*Cydia* sp.	Torticidiae	Lepidoptera
Rice horned caterpillar	*Melanitis leda ismene* Cr.	Nymphalidae	Lepidoptera
Rice skipper	*Pelopidas mathias mathias* Fb.	Hesperiidae	Lepidoptera
	Dinara combusta (Wlk.)	Notodontidae	Lepidoptera
Redhairy caterpillar	*Amsacta albistriga* M.	Arctiidae	Lepidoptera
	A. lactinea (Cr.)	Arctiidae	Lepidoptera
	A. moorei Butl.	Arctiidae	Lepidoptera
Greasy cutworm	*Agrotis ipsilon* (Hufn.)	Noctuidae	Lepidoptera
	A. spinifera (Hubn.)	Noctuidae	Lepidoptera
	Anticarsia irrorata F.	Noctuidae	Lepidoptera
Green semilooper	*Azazia rubricans* B.	Noctuidae	Lepidoptera
Earhead caterpillar	*Celama internella* Wlk.	Noctuidae	Lepidoptera
Earhead caterpillar	*Eublemma sp. nr. gayneri* Roths.	Noctuidae	Lepidoptera
	E. hemirrhoda Wlk.	Noctuidae	Lepidoptera
	E. silicula Swinh.	Noctuidae	Lepidoptera
Gram pod borer	*Helicoverpa armigera* Hb.	Noctuidae	Lepidoptera
Cutworm	*Mythimna separata* (Wlk.)	Noctuidae	Lepidoptera
	M. lorey (Dup.)	Noctuidae	Lepidoptera

Pink borer	*Sesamia inferens* Wlk.	Noctuidae	Lepidoptera
Sorghum stalk caterpillar	*Simplicia robustalis* G.	Noctuidae	Lepidoptera
	Euproctis limbata Wlk.	Lymantriidae	Lepidoptera
	Porthesia xanthorrhoea Koll.	Lymantriidae	Lepidoptera
Stemfly or shootfly	*Atherigona varia soccata* Rond.	Anthomyiidae	Diptera
	A. orientalis Schiner	Anthomyiidae	Diptera
Gall midge	*Stenadiplosis sorghicola* (Coq.)	Cecidomyiidae	Diptera
Seed ants	*Monomorium salomonis* L.	Formicidae	Hymenoptera
	Pheidole sulcaticeps var.*punensis* For.	Formicidae	Hymenoptera
Earhead chafer	*Anatona stillata* Newm.	Cetoniidae	Coleoptera
	Anthracophora crucifera Oliv.	Cetoniidae	Coleoptera
	Chiloboba acuta W.	Cetoniidae	Coleoptera
	Heterorhina elegans Fb.	Cetoniidae	Coleoptera
	Oxycetonia albopunctata Fb.	Cetoniidae	Coleoptera
	O. versicolor F.	Cetoniidae	Coleoptera
	Protaetia alboguttata Vig.	Cetoniidae	Coleoptera
	P. aurichalcea F.	Cetoniidae	Coleoptera
	Pachyrhinadoretus rugipennis Ohaus	Cetoniidae	Coleoptera
	Rhinyptia indica Burm.	Cetoniidae	Coleoptera
	Anomala bengalensis Blanch.	Rutelidae	Coleoptera
White grub	*Holotrichia consanguinea* Blanch.	Melolonthidae	Coleoptera
	H. insularis Brenske	Melolonthidae	Coleoptera
Earhead blister beetle	*Cylindrothorax tenuicollis* P.	Meloidae	Coleoptera
	Gnathospastoides rouxi C.	Meloidae	Coleoptera
	Lytta actaeon Cast.	Meloidae	Coleoptera
	Rhyzopertha dominica F.	Bostrychidae	Coleoptera
	Astycus lateralis Fb.	Curculionidae	Coleoptera
	Myllocerus discolor F.	Curculionidae	Coleoptera
	M. maculosus Desbr.	Curculionidae	Coleoptera
Rice weevil	*Sitophilus oryzae* Linn.	Curculionidae	Coleoptera
	Tanymecus indicus Fst.	Curculionidae	Coleoptera
	Cryptocephalus schestedti	Cryptocephalidae	Coleoptera
	Monolepta signata O.	Galerucidae	Coleoptera
	Pachnephorus bretinghami Baly	Eumolpidae	Coleoptera
Leaf miner	*Pseudonapomyza gujaratica*	Agromyzidae	Diptera

Zea mays (MAIZE)

Grasshopper	*Hieroglyphus nigrorepletus* (Bol.)	Acrididae	Orthoptera
Wingless grasshopper	*Neorthacris elegans* B.	Acrididae	Orthoptera
Rice small grasshopper	*Oxya nitidula* Willemse	Acrididae	Orthoptera
Field cricket	*Brachytrypes portentosus* (Licht.)	Gryllidae	Orthoptera
Field cricket	*Gryllopsis* sp.	Gryllidae	Orthoptera
Field cricket	*Loxoblemmus macrocephalus* (Chopard)	Gryllidae	Orthoptera

Field cricket	*Modicogryllus minimus* (Chopard)	Gryllidae	Orthoptera
Field cricket	*Teleogryllus mitratus* (Burmeister)	Gryllidae	Orthoptera
	Velarifictorus sp.	Gryllidae	Orthoptera
Sugarcane pyrilla	*Pyrilla perpusilla* Wlk.	Lophopidae	Hemiptera
	Tricentrus bicolor Dist.	Membracidae	Hemiptera
	Leptocentrus obliquus W.	Membracidae	Hemiptera
	Eoevrysa sp.	Delphacidae	Hemiptera
Corn lantern fly	*Peregrinus maidis* Ashm.	Delphacidae	Hemiptera
	Proutista moesta (Westw.)	Derbidae	Hemiptera
Rusty plum aphid	*Hysteroneura setariae* (Thomas)	Aphididae	Hemiptera
	Rhopalosiphum maidis Fitch.	Aphididae	Hemiptera
	Cerococcus hibisci Gr.	Asterolecaniidae	Hemiptera
	Euridema pulchrus West.	Pentatomidae	Hemiptera
Frog hopper	*Ptyelus sexvittatus* Walker	Cercopidae	Hemiptera
Rice black bug	*Scotinophara lurida* (Burm.)	Podopidae	Hemiptera
Thrips	*Anaphothrips sudanensis* Trybom	Thripidae	Thysanoptera
	Caliothrips graminicola (B. & C.)	Thripidae	Thysanoptera
	Haplothrips gowdeyi (Franklin)	Phlaeothripidae	Thysanoptera
	Anatrachyntis simplex Wlsm.	Cosmopterygidae	Lepidoptera
Angoumois grain moth	*Sitotroga cerealella* Oliv.	Gelechiidae	Lepidoptera
Gurdaspur borer	*Bissetia steniella* (Hmpsn.)	Pyralidae	Lepidoptera
Gold fringed borer	*Chilo auricilius* (Dudgeon)	Pyralidae	Lepidoptera
Sorghum stem borer	*C. partellus* (Swinh.)	Pyralidae	Lepidoptera
Leaf roller	*Cnaphalorcrocis trapezalis* (Guen. O	Pyralidae	Lepidoptera
Cob caterpillar	*Cryptoblabes angustipennella* Hmpsn	Pyralidae	Lepidoptera
Indian meal moth	*Plodia interpunctella* Hubn.	Pyralidae	Lepidoptera
Sugarcane green borer	*Raphimetopus ablutella* Zeller	Pyralidae	Lepidoptera
Cob caterpillar	*Stenachroia elongella* Walk.	Pyralidae	Lepidoptera
Rice skipper	*Pelopidas mathias mathias* Fb.	Hesperiidae	Lepidoptera
Red hairy caterpillar	*Amsacta moorei* Butl.	Arctiidae	Lepidoptera
Bihar hairy caterpillar	*Spilarctia obliqua* (Wlk.)	Arctiidae	Lepidoptera
Silk cutter	*Euproctis virgincula* Walker	Lymantriidae	Lepidoptera
Cutworm	*Agrotis ipsilon* (Hufn.)	Noctuidae	Lepidoptera
	A. spinifera Hubn.	Noctuidae	Lepidoptera
	A. ypsilon (Rott.)	Noctuidae	Lepidoptera
	Mythimna separata (Walk.)	Noctuidae	Lepidoptera
Gram pod borer	*Helicoverpa armigera* (Hb.)	Noctuidae	Lepidoptera
	M. Loreyi (Dup.)	Noctuidae	Lepidoptera
Pink stem borer	*Sesamia inferens* Wlk.	Noctuidae	Lepidoptera
Cutworm	*Spodoptera exigua* (Hubn.)	Noctuidae	Lepidoptera
	S. litura (Fb.)	Noctuidae	Lepidoptera
Stem fly	*Atherigona orientalis* Schiner	Anthomyiidae	Diptera
Leaf miner	*Pseudonapomyza gujaratica*	Agromyziadae	Diptera
White grub	*Holotrichia consanguinea* Blanch.	Melolonthidae	Coleoptera
	H. insularis Brenske	Melolonthidae	Coleoptera
Flower beetle	*Chiloloba acuta* Wiedmann	Cetoniidae	Coleoptera

	Oxycetonia versicolor W.	Cetoniidae	Coleoptera
	Protaetia alboguttata Vig.	Cetoniidae	Coleoptera
Blister beetle	*Mylabris macilenta* Mshl.	Meloidae	Coleoptera
	M. phalerata Pall.	Meloidae	Coleoptera
	M. pustulata Thunb.	Meloidae	Coleoptera
	M. tiflensis Billb.	Meloidae	Coleoptera
Seed beetle	*Amblystomus bivittatus* Andr.	Carabidae	Coleoptera
Seed beetle	*Apristus subtransparens* Mots.	Carabidae	Coleoptera
Seed beetle	*Tachys fumigatus* Mots.	Carabidae	Coleoptera
Seed beetle	*Anthicus crinitus* Laf.	Anthicidae	Coleoptera
Seedling beetle	*Heteronychus lioderes* Redt.	Dynastidae	Coleoptera
	Rhyzopertha dominica F.	Bostrychidae	Coleoptera
Flea beetle	*Chaetocnema basalis* Baly.	Alticidae	Coleoptera
Leaf beetle	*Myllocerus discolor* F.	Curculionidae	Coleoptera
Rice weevil	*Sitophilus oryzae* Linn.	Curculionidae	Coleoptera

SUGARS

Saccharum officinarum (SUGARCANE)

Grasshopper	*Atractomorpha crenulata* F.	Acrididae	Orthoptera
	Chondracris rosea Deg.	Acrididae	Orthoptera
	Choroedocus illustris Wlk.	Acrididae	Orthoptera
Wingless grasshopper	*Colemania sphenarioides* Bol.	Acrididae	Orthoptera
	Gastrimargus marmoratus Thu.	Acrididae	Orthoptera
	G. transversus Thu.	Acrididae	Orthoptera
Rice grasshopper	*Hieroglyphus banian* F.	Acrididae	Orthoptera
	H. concolor Wlk.	Acrididae	Orthoptera
	H. oryzivorus Carl.	Acrididae	Orthoptera
	H. nigrorepletus Bol.	Acrididae	Orthoptera
	Locusta migratoria L.	Acrididae	Orthoptera
	L. solitaria L.	Acrididae	Orthoptera
	Neorthacris aculiceps niligiriensis (Uvarov)	Acrididae	Orthoptera
	Oedaleus infernalis Sauss	Acrididae	Orthoptera
Rice small grasshopper	*Oxya bidentata* Willemse	Acrididae	Orthoptera
	O. bilabyla Saville	Acrididae	Orthoptera
	O. multidentata Willemse	Acrididae	Orthoptera
	O. uvarovi Willemses	Acrididae	Orthoptera
	O. velox F.	Acrididae	Orthoptera
	Patanga luteicornis Serv.	Acrididae	Orthoptera
	P. succincta L.	Acrididae	Orthoptera
	Poekilocerus hieroglyphicus Klug.	Pyrgomorphidae	Orthoptera
Termite	*Coptotermes heimi* (Wasmann)	Rhincotermitidae	Isoptera
	Eremotermes paradoxalis Holmgren	Termitidae	Isoptera
	Microcerotermes beesoni Synder	Termitidae	Isoptera
	Microtermes obesi Holmgr.	Termitidae	Isoptera

	M. mycophagus (Desneux)	Termitidae	Isoptera
	Macrotermes estherae (Desneux)	Termitidae	Isoptera
	Odontotermes assumthi Holmgr.	Termitidae	Isoptera
	O. obesus Rhamb.	Termitidae	Isoptera
	O. gurdaspurensis Holmgren	Termitidae	Isoptera
	O. redemanni (Wasmann)	Termitidae	Isoptera
	O. taprobanes (Walker)	Termitidae	Isoptera
	O. wallonensis (Wasmann)	Termitidae	Isoptera
	Trinervitermes biformis (Wasmann)	Termitidae	Isoptera
Cowbug	*Tricentrus bicolor* Dist.	Membracidae	Hemiptera
	Leptocentrus obliquus W.	Membracidae	Hemiptera
	Arborida sp.	Cicadellidae	Hemiptera
	Balclutha salutella (Kirschbaum)	Cicadellidae	Hemiptera
White leafhopper	*Cofana spectra* (D.)	Cicadellidae	Hemiptera
	C. subvirescens (Staol.)	Cicadellidae	Hemiptera
	Doratulina rubrolineata (Distant)	Cicadellidae	Hemiptera
Brown-backed planthopper	*Nilaparvata lugens* (Stal.)	Delphacidae	Hemiptera
	Eoeuryma bispinosa Mammen & Menon	Delphacidae	Hemiptera
	Peregrinus maidis Ashm.	Delphacidae	Hemiptera
White-backed planthopper	*Sogatella furcifera* (Horv.)	Delphacidae	Hemiptera
	Tropidocephala marginepunctata (Mel.)	Delphacidae	Hemiptera
	T. saccharivorella Mats.	Delphacidae	Hemiptera
	T. serendiba (Melichar)	Delphacidae	Hemiptera
	T. signata (Dist.)	Delphacidae	Hemiptera
	Parabolocratus porrectus Wlk.	Delphacidae	Hemiptera
	Perkinsiella saccharivora (?) Muir	Delphacidae	Hemiptera
	Proutista moesta (West.)	Derbidae	Hemiptera
	Diostrombus carnosus Westw.	Derbidae	Hemiptera
Sugarcane pyrilla	*Pyrilla perpusilla* Wlk.	Lophopidae	Hemiptera
	Kusuma carinata Dist.	Lophopidae	Hemiptera
	Elasmoscelis platypoda Kirby	Fulgoridae	Hemiptera
	Orchesma marginipunctata Melich	Fulgoridae	Hemiptera
	O. serendiba Melich	Fulgoridae	Hemiptera
	Aphrophora sigillifera Wlk.	Cercopidae	Hemiptera
	Callitettix versicolor F.	Cercopidae	Hemiptera
Leafhopper	*Yamatotettix* (*Pruthiana*) *sexnotata* (Izzard)	Nirvaniidae	Hemiptera
Sugarcane aleyrodid	*Aleurolobus barodensis* Mask.	Aleyrodidae	Hemiptera
	Bemisia tabaci (Gennadius)	Aleyrodidae	Hemiptera
Sugarcane aleyrodid	*Neomaskellia andropogonis* Corbett	Aleyrodidae	Hemiptera
	N. bergii Sign.	Aleyrodidae	Hemiptera
Woolly aphid	*Ceratovacuna lanigera* (Zehtner)	Aphididae	Hemiptera
	Forda orientalis George	Aphididae	Hemiptera
Root aphid	*Geocia spatulata* Theo.	Aphididae	Hemiptera
	Melanaphis indosacchari (D.)	Aphididae	Hemiptera

	M. sacchari (Zehnt.)	Aphididae	Hemiptera
	Rhopalosiphum maidis Fitch.	Aphididae	Hemiptera
Root aphid	*Tetraneura coimbatorensis* George	Aphididae	Hemiptera
	T. hirsuta Baker	Aphididae	Hemiptera
	Tetraneura javensis vd.G.	Aphididae	Hemiptera
	T. kalimpongensis Roychaudhuri	Aphididae	Hemiptera
Rusty plum aphid	*Hysteroneura setariae* (Thomas)	Aphididae	Hemiptera
	Ceratovacuna graminum Zehnt.	Aphididae	Hemiptera
Leaf scale	*Marsipococcus* sp.	Coccidae	Hemiptera
	Ceroplastes actiniformis Green	Coccidae	Hemiptera
	Pulvinaria elongata Newstead	Coccidae	Hemiptera
	Saccharolecanium krugeri (Zehtner)	Coccidae	Hemiptera
	Antonina graminis (Maskell)	Pseudococcidae	Hemiptera
	Dysmicoccus breviceps (Ckll.)	Pseudococcidae	Hemiptera
	D. carens Williams	Pseudococcidae	Hemiptera
	Kiritshenkella sacchari (Green)	Pseudococcidae	Hemiptera
	Phenacoccus saccharifolii (Green)	Pseudococcidae	Hemiptera
	Pseudococcus saccharicola Takahashi	Pseudococcidae	Hemiptera
Root mealy bug	*Saccharicoccus sacchari* Ckll.	Pseudococcidae	Hemiptera
	Trionymus sacchari Ckll.	Pseudococcidae	Hemiptera
	Icerya pilosa nardi Gr.	Margarodidae	Hemiptera
	Aclerda distorta G.	Aclerdidae	Hemiptera
	A. japonica N.	Aclerdidae	Hemiptera
	A. japonica var. inermis Gr.	Aclerdidae	Hemiptera
	Acanthomytilus sacchari (Hall)	Diaspididae	Hemiptera
	Aspidiella sacchari Cockerell	Diaspididae	Hemiptera
	Aulacaspis madiunensis (Zehntner)	Diaspididae	Hemiptera
	Duplachionaspis divergens (Green)	Diaspididae	Hemiptera
	Greenaspis decurvata (Green)	Diaspididae	Hemiptera
	Lepidosaphes sacchari Hall.	Diaspididae	Hemiptera
	Melanaspis glomerata (Green)	Diaspididae	Hemiptera
	Odonaspis saccharicaulis (Zehnt.)	Diaspididae	Hemiptera
	Temnaspidiotus kellyi (Br.)	Diaspididae	Hemiptera
Sugarcane black bug	*Cavelerius sweeti* Slater & Mugomoto	Lygaeidae	Hemiptera
	Dimorphopterus gibbus F.	Lygaeidae	Hemiptera
	Spilostethus macilentus Stal.	Lygaeidae	Hemiptera
Rice bug	*Leptocorisa acuta* (Thunb.)	Alydidae	Hemiptera
	Cletus bipunctatus Westw.	Coreidae	Hemiptera
Rice black bug	*Scotinophara lurida* (Thunb.)	Podopidae	Hemiptera
Plant bug	*Agonoscelis nubila* F.	Pentatomidae	Hemiptera
	Bagrada cruciferarum Kirk.	Pentatomidae	Hemiptera
	Menida histrio F.	Pentatomidae	Hemiptera
	Abdastartus atrus (Motsch,)	Tingidae	Hemiptera
Lace wing bug	*Bako malayanus* (Drake)	Tingidae	Hemiptera

	Teleonemia sacchari F.	Tingidae	Hemiptera
	Aeolothrips collaris Pr.	Aeolothripdae	Thysanoptera
	A. sudanensis Trybom	Thripidae	Thysanoptera
	Bregmatothrips binervis (Kobus)	Thripidae	Thysanoptera
	Dichromothrips smithi (Zimm.)	Thripidae	Thysanoptera
	Exothrips sacchari (Shumsher)	Thripidae	Thysanoptera
	Florithrips traegardhi (Trybom)	Thripidae	Thysanoptera
	Thrips saccharicidus (Ayyar & Marg.)	Thripidae	Thysanoptera
	Sorghothrips jonnaphilus (Ramk.)	Thripidae	Thysanoptera
	Stenchaetothrips indicus (R. & M.)	Thripidae	Thysanoptera
	Haplothrips tolerabilis Priesner	Phlaeothripidae	Thysanoptera
	Procametis trochala Meyr.	Cryptophasidae	Lepidoptera
Slug caterpillar	*Parasa bicolor* Wlk.	Limacodiidae	Lepidoptera
Gurdaspur borer	*Bissetia steniella* (Hmpsn.)	Pyralidae	Lepidoptera
Borer	*A. tauromma* Kapur	Pyralidae	Lepidoptera
Gold-fringed borer	*Chilo auricilius* (Dudgeon)	Pyralidae	Lepidoptera
Sugarcane shoot borer	*C. infuscatellus* Snellen	Pyralidae	Lepidoptera
Sorghum stem borer	*C. partellus* (Swinhoe)	Pyralidae	Lepidoptera
Stem borer	*Chilo sacchariphagus indicus* (Kapur)	Pyralidae	Lepidoptera
	C. tumidicostalis Hampson	Pyralidae	Lepidoptera
Leaf roller	*Cnaphalocrocis medinalis* Guen.	Pyralidae	Lepidoptera
	C. suspicalis W.	Pyralidae	Lepidoptera
	C. tradpezalis (Guen.)	Pyralidae	Lepidoptera
Root borer	*Emmalocera depresselis* Swinh.	Pyralidae	Lepidoptera
	Herpetogramma phaeopteralis (Guen.)	Pyralidae	Lepidoptera
	Pyrausta coclesalis Wlk.	Pyralidae	Lepidoptera
Green borer	*Raphimetopus ablutella* Zell.	Pyralidae	Lepidoptera
Top borer	*Scirpophaga exceptalis* Walker	Pyralidae	Lepidoptera
Rice skipper	*Pelopidas mathias mathias* (Fb.)	Hesperiidae	Lepidoptera
Sugarcane skipper	*Telicota augias* L.	Hesperiidae	Lepidoptera
	Danus limniace Cram.	Danaidae	Lepidoptera
Cutworm	*Agrotis ypsilon* (Rott.)	Noctuidae	Lepidoptera
	A. spinifera (Hubn.)	Noctuidae	Lepidoptera
	Laphygma exigua Hb.	Noctuidae	Lepidoptera
	Mythimna albistigma (Moore)	Noctuidae	Lepidoptera
	M. loreyi (Dup.)	Noctuidae	Lepidoptera
	M. separata (Walk.)	Noctuidae	Lepidoptera
	M. unipuncta (Haul.)	Noctuidae	Lepidoptera
Pink stem borer	*Sesamia inferens* Wlk.	Noctuidae	Lepidoptera
	Spodoptera mauritia Boisd.	Noctuidae	Lepidoptera
	Creatonotus gangis Linn.	Arctiidae	Lepidoptera

	Spilarctia obliqua (Wlk.)	Arctiidae	Lepidoptera
Borer	*Phragmatoecia purpurea* Fletcher	Cosssidae	Lepidoptera
Borer	*P. terebrifer* Fletcher	Cosssidae	Lepidoptera
	Acanthopsyche sp.	Psychidae	Lepidoptera
	Mahasena graminivora Hampson	Psychidae	Lepidoptera
	Leucophlebia lineata Westw.	Lymantriidae	Lepidoptera
	Nygmia xanthorrhoea Koll.	Lymantriidae	Lepidoptera
	Psalis pennatula F.	Lymantriidae	Lepidoptera
Root ant	*Dorylus orientalis* Westwood	Formicidae	Hymenoptera
	Apogonia proxima Waterh.	Melolonthidae	Coleoptera
	Autoserica insanabilis Brenske	Melolonthidae	Coleoptera
White grub	*Holotrichia consanguinea* Blanch.	Melolonthidae	Coleoptera
	H. insularis Brenske	Melolonthidae	Coleoptera
	H. serrata (Fabr.)	Melolonthidae	Coleoptera
	Lepidiota mansueta Brrm.	Melolonthidae	Coleoptera
	Leucopholis lepidophora Blanch	Melolonthidae	Coleoptera
	Phyllognathus dionysius Fabr.	Melolonthidae	Coleoptera
	Schizonycha ruficollis Fabr.	Melolonthidae	Coleoptera
	Serica assamensis Brenske	Melolonthidae	Coleoptera
	S. vulgaris Brenske	Melolonthidae	Coleoptera
	Alissonotum impressicolle Arrow	Dynastidae	Coleoptera
	A. simile Arrow	Dynastidae	Coleoptera
	A. piceum Fb.	Dynastidae	Coleoptera
	Euetheola rugiceps Lec.	Dynastidae	Coleoptera
	Heteronychus sublaevis F.	Dynastidae	Coleoptera
	H. robustus Arrow	Dynastidae	Coleoptera
Coconut black beetle	*Oryctes rhinoceros* Linn.	Dynastidae	Coleoptera
	Pentodon bengalensis Arrow	Dynastidae	Coleoptera
	P. bispinifrons Reitt.	Dynastidae	Coleoptera
	Adoretus caliginosus Burm.	Rutelidae	Coleoptera
	A. versutus Har.	Rutelidae	Coleoptera
	Anomala bengalensis Blanch	Rutelidae	Coleoptera
	A. biharensis Arrow	Rutelidae	Coleoptera
	A. dorsalis Fabr.	Rutelidae	Coleoptera
	A. dussumieri Blanch	Rutelidae	Coleoptera
	A. varciolor Gyll.	Rutelidae	Coleoptera
Leaf scraper	*Asmangulia cuspidata* M.	Hispidae	Coleoptera
	Leptispa pygmaea B.	Hispidae	Coleoptera
	Philodonta modesta W.	Hispidae	Coleoptera
	Rhadinosa sp.	Hispidae	Coleoptera
Leaf beetle	*Amblyrrhinus poricollis* Boh.	Curculionidae	Coleoptera
	Myllocerus blandus Fst.	Curculionidae	Coleoptera
	M. dentifer F.	Curculionidae	Coleoptera
	M. discolor F.	Curuclionidae	Coleoptera
	M. 11-pustulatus	Curculionidae	Coleoptera
	M. undecimpustulatus Fst.	Curculionidae	Coleoptera
	Tanymecus hispidus Marshall	Curculionidae	Coleoptera

	T. sciurus F.	Curculionidae	Coleoptera
	Telincame paria Fairm.	Curculionidae	Coleoptera
	Lychrosis zebrina F.	Lamiidae	Coleoptera
	Dinoderus minutus F.	Bostrychidae	Coleoptera
	Monolepta signata Iliv.	Galerucidae	Coleoptera
	Haplosoryx elongatus Baly.	Eumolpidae	Coleoptera
	Pachnephorus bretinghami Jac.	Eumolpidae	Coleoptera
	P. impressus Rosenh.	Eumolpidae	Coleoptera

FIBRE CROPS

Corchorus capsularis and C. olitorius (JUTE)

Surface grasshopper	*Atractomorpha crenulata* Fb.	Acrididae	Orthoptera
Ground cricket	*Brachytrapes portentosus* Licht.	Gryllidae	Orthoptera
White ant	*Microtermes obesi* Holmgr.	Termitidae	Isoptera
Cowbug	*Otinotus elongatus* Dist.	Membracidae	Hemiptera
White tailed mealybug	*Ferrisia virgata* (Ckll.)	Pseudococcidae	Hemiptera
	Maconellicoccus hirsutus (Green)	Pseudococcidae	Hemiptera
Mealy bug	*Nipaecoccus vastator* (Maskell)	Pseudococcidae	Hemiptera
Scale insect	*Parasaissetia nigra* (Nietn.)	Coccidae	Hemiptera
	Pinnaspis sp.	Diaspididae	Hemiptera
Leaf thrips	*Ayyaria chaetophora* Karny	Thripidae	Thysanoptera
Woolly bear	*Amsacta lactinea* (Cr.)	Arctiidae	Lepidoptera
Bihar hairy caterpillar	*Spilarctia obliqua* (Wlk.)	Arctiidae	Lepidoptera
Jute semilooper	*Anomis sabulifera* Guen.	Noctuidae	Lepidoptera
Pod borer	*Earias chromataria* Cr.	Noctuidae	Lepidoptera
	E. cupreoviridis Cr.	Noctuidae	Lepidoptera
Safflower caterpillar	*Condica capensis* (Guen.)	Noctuidae	Lepidoptera
Green semilooper	*Chrysodeixis eriosoma* (D.)	Noctuidae	Lepidoptera
	Spodoptera exigua (Hb.)	Noctuidae	Lepidoptera
Tobacco caterpillar	*S. litura* (F.)	Noctuidae	Lepidoptera
	Tarache crocata Guen.	Noctuidae	Lepidoptera
Tussock caterpillar	*Olene mendosa* Hb.	Lymantriidae	Lepidoptera
	Porthesia scintillans Wlk.	Lymantriidae	Lepidoptera
Jute stem borer	*Agrilus acutus* Thunb.*	Buprestidae	Coleoptera
Leaf miner	*Trachys dasi* Thery	Buprestidae	Coleoptera
	T. pacifica Kerr.	Buprestidae	Coleoptera
Wire worm	*Agriotes* sp.	Elateridae	Coleoptera
	Epicauta sp.	Meloidae	Coleoptera
Stem-girdler	*Nupserha bicolor postbrunnea* Dutt	Cerambycidae	Coleoptera
	Cleoporus lefevrei D.	Eumolpidae	Coleoptera
	Nodostoma bengalensis Duriv.	Eumolpidae	Coleoptera
	Pachnephorus bretinghami Baly.	Eumolpidae	Coleoptera
Jute stem weevil	*Apion corchori* Mshll.	Apionidae	Coleoptera

* Infests *C. olitorius* alone

Gossypium **spp. (COTTON)**

Surface grasshopper	*Acrida exaltata* Wlk.	Acrididae	Orthoptera
	Aiolopus tamulus (Fb.)	Acrididae	Orthoptera
	Atractomorpha crenulata F.	Acrididae	Orthoptera
	Catantops annexus Bol.	Acrididae	Orthoptera
Cotton grasshopper	*Cyrtacanthacris ranacea* Stoll.	Acrididae	Orthoptera
	C. rosea Deg.	Acrididae	Orthoptera
Rice smaller grasshopper	*Oxya nitidula* Willemse	Acrididae	Orthoptera
Bombay locust	*Patanga succincta* (Linn.)	Acrididae	Orthoptera
'AK' grasshopper	*Poekilocerus pictus* Fb.	Acrididae	Orthoptera
Desert locust	*Schistocerca gregaria* (Forsk.)	Acrididae	Orthoptera
	Chrotogonus brachypterus (BI.)	Pyrgomorphidae	Orthoptera
	C. oxypterus (BI.)	Pyrgomorphidae	Orthoptera
	C. saussurei Boll.	Pyrgomorphidae	Orthoptera
Large Brown cricket	*Brachytrypes portentosus* Licht.	Gryllidae	Orthoptera
Black headed cricket	*Gryllus domesticus* Linn.	Gryllidae	Orthoptera
	G. mitratus Burmeister	Gryllidae	Orthoptera
Cricket	*G. viator* Kirby	Gryllidae	Orthoptera
White ant	*Microtermes obesi* Holmgr.	Termitidae	Isoptera
	Odontotermes obesus (Ramb.)	Termitidae	Isoptera
Groundnut earwig	*Euborellia annulipes* Lucas	Forficulidae	Dermaptera
	Machaerota ensifera Burm.	Cercopidae	Hemiptera
Tube making cercopid	*M. planitiae* Dist.	Cercopidae	Hemiptera
Cowbug	*Leptocentrus obliquus* W.	Membracidae	Hemiptera
	Otinotus oneratus Wlk.	Membracidae	Hemiptera
	Tricentrus bicolor Dist.	Membracidae	Hemiptera
Leafhopper	*Empoasca devastans* Dist.	Cicadellidae	Hemiptera
	E. formosana Paoli	Cicadellidae	Hemiptera
	E. gossypii Banks	Cicadellidae	Hemiptera
	E. kerri var. motti Purthi	Cicadellidae	Hemiptera
	E. minor Pruthi	Cicadellidae	Hemiptera
	E. notata Mell.	Cicadellidae	Hemiptera
	E. punjabensis Pruthi	Cicadellidae	Hemiptera
	Kushala maculata D.	Cicadellidae	Hemiptera
	Ricania fenestrata Fab.	Ricaniidae	Hemiptera
	Eurybrachys tomentosa Fb.	Eurybrachidae	Hemiptera
Cotton white fly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	Hemiptera
	Trialeurodes ricini (Misra)	Aleyrodidae	Hemiptera
Cotton aphid	*Aphis gossypii* Glover	Aphididae	Hemiptera
Tailed mealy bug	*Ferrisia virgata* (Ckll.)	Pseudococcidae	Hemiptera
	Maconellicoccus hirsutus (Green)	Pseudococcidae	Hemiptera
	Phenacoccus iceryoides Green	Pseudococcidae	Hemiptera
	Planococcus sp.	Pseudococcidae	Hemiptera
	Nipaecoccus vastator (Mask.)	Pseudococcidae	Hemiptera
Neem scale	*Chloropulvinaria maxima* Green	Coccidae	Hemiptera
	Parasaissetia nigra (Nietner)	Coccidae	Hemiptera

	Cerococcus hibisci Green	Asterolecaniidae	Hemiptera
Tea-mosquito bug	*Helopeltis antonii* Sign.	Miridae	Hemiptera
	Ragmus flavomaculatus Ballard	Miridae	Hemiptera
Sunnhemp mirid	*R. importunitas* Dist.	Miridae	Hemiptera
	R. morosus Ballard	Miridae	Hemiptera
	Spilostethus hospes Fb.	Lygaeidae	Hemiptera
	S. pandurus (Scop.)	Lygaeidae	Hemiptera
Dusky cotton bug	*Oxycarenus hyalinipennis* Costa	Lygaeidae	Hemiptera
Red cotton bug	*Dysdercus cingulatus* (Fb.)	Pyrrhocoridae	Hemiptera
	D. olivaceus Fb.	Pyrrhocoridae	Hemiptera
	Clavigralla horrens D-	Coreidae	Hemiptera
	Serinatha augur Fb	Coreidae	Hemiptera
Plant bug	*Nezara viridula* Linn.	Pentatomidae	Hemiptera
	Astropthrips parvilimbus S. & M.	Thripidae	Thysanoptera
	Caliothrips indicus Bagnall	Thripidae	Thysanoptera
	Frankliniella sulphurea Schm.	Thripidae	Thysanoptera
Castor thrips	*Retithrips syriacus* (Mayet)	Thripidae	Thysanoptera
Chilly thrips	*Scirtothrips dorsalis* Hood	Thripidae	Thysanoptera
	S. oligochaetus Karny	Thripidae	Thysanoptera
	Thrips flavus Schrank	Thripidae	Thysanoptera
Onion thrips	*T. tabaci* Lind.	Thripidae	Thysanoptera
Pink bollworm	*Pectinophora gossypiella* Saund	Gelechiidae	Lepidoptera
	Anatrachyntis simplex Wlsm.	Cosmopterygidae	Lepidoptera
	Pyroderces gossypiella Sn.	Cosmopterygidae	Lepidoptera
Leaf miner	*Acrocercops zygonoma* Meyr.	Gracillariidae	Lepidoptera
Leaf perforator	*Bucculatrix loxophila* Meyr.	Gracillariidae	Lepidoptera
	Lithocolletis triarcha Meyr.	Gracillariidae	Lepidoptera
Red coffee borer	*Zeuzera coffeae* Nietn.	Zeuzeridae	Lepidoptera
Castor capsule borer	*Conogethes punctiferalis* Guen.	Pyralidae	Lepidoptera
Rice meal worm	*Corcyra cephalonica* St.	Pyralidae	Lepidoptera
Bud worm	*Phycita infusella* Meyr.	Pyralidae	Lepidoptera
Leaf roller	*Syllepte derogata* Fb.	Pyralidae	Lepidoptera
Red hairy caterpillar	*Amsacta albistriga* W.	Arctiidae	Lepidoptera
Black hairy caterpillar	*A. lactinea* (Cram.)	Arctiidae	Lepidoptera
	A. moorei Butl.	Arctiidae	Lepidoptera
Woolly bear	*Pericallia ricini* F.	Arctiidae	Lepidoptera
Bihar hairy caterpillar	*Spilarctia obliqua* (Wlk.)	Arctiidae	Lepidoptera
	Acontia graellsi F.	Noctuidae	Lepidoptera
	A. intersepta Guen.	Noctuidae	Lepidoptera
	A. malvae Esper	Noctuidae	Lepidoptera
Cutworm	*Agrotis flammatra* Schiff.	Noctuidae	Lepidoptera
	A. segetum (Schiff.)	Noctuidae	Lepidoptera
	A. spinifera (Hubn.)	Noctuidae	Lepidoptera
Green semilooper	*Anomis flava* Fb.	Noctuidae	Lepidoptera
	A. fulvida Guen.	Noctuidae	Lepidoptera
Spiny bollworm	*Earias insulana* Boisd.	Noctuidae	Lepidoptera
Spotted bollworm	*E. vittella* (F.)	Noctuidae	Lepidoptera

Gram caterpillar	*Helicoverpa armigera* (Hb.)	Noctuidae	Lepidoptera
Semilooper	*Mocis undata* Fb.	Noctuidae	Lepidoptera
Cutworm	*Mythimna loreyi* (Dup.)	Noctuidae	Lepidoptera
Red bollworm	*Rabila frontalis* Wlk.	Noctuidae	Lepidoptera
Leaf caterpillar	*Spodoptera exigua* (Hb.)	Noctuidae	Lepidoptera
	S. litura (F.)	Noctuidae	Lepidoptera
	S. pecten Gn.	Noctuidae	Lepidoptera
Semilooper	*Tarache basifera* Wlk.	Noctuidae	Lepidoptera
	T. mormoralis F.	Noctuidae	Lepidoptera
	T. nitidula Fb.	Noctuidae	Lepidoptera
Semilooper	*T. notabilis* Wlk.	Noctuidae	Lepidoptera
	T. opalinoides Guen.	Noctuidae	Lepidoptera
Tussock caterpillar	*Euproctis fraterna* Moore	Lymantriidae	Lepidoptera
	E. lunata Wlk.	Lymantriidae	Lepidoptera
	E. varians Wlk.	Lymantriidae	Lepidoptera
	Lymantria ampla Walker	Lymantriidae	Lepidoptera
	Porthesia xanthorrhoea Koll.	Lymantriidae	Lepidoptera
Floral bud maggot	*Dasyneua gossypii* Felt.	Cecidomyiidae	Diptera
Cotton fly	*Metopostigma sauteri* B.	Chloropidae	Diptera
Sepentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Leaf ant	*Solenopsis geminata* Fb.	Formicidae	Hymenoptera
Stem borer	*Sphenoptera gossypii* Cotes	Buperstidae	Coleoptera
	Sinoxylon sudanicum Lesne	Bostrychidae	Coleoptera
	Alphitobius laevigatus F.	Tenebrionidae	Coleoptera
Blister beetle	*Mylabris pustulata* (Thunb.)	Meloidae	Coleoptera
	Colasposoma auripenne Motsch.	Eumolpidae	Coleoptera
	Monolepta signata O1.	Galerucidae	Coleoptera
	Araecerus fasciculatus Deg.	Anthribidae	Coleoptera
Stem weevil	*Alcidodes affaber* Auriv.	Curculionidae	Coleoptera
	A. fabrici Fb.	Curculionidae	Coleoptera
	A. mysticus Fst.	Curculionidae	Coleoptera
Flower weevil	*Amorphoidae arcuata* M.	Curculionidae	Coleoptera
Green weevil	*Astycus lateralis* Fb.	Curculionidae	Coleoptera
Surface weevil	*Atactogaster finitimus*	Curculionidae	Coleoptera
	Episomus lacerta F.	Cuculionidae	Coleoptera
	Lepropus lateralis F.	Curculionidae	Coleoptera
	Myllocerus blandus Fst.	Curculionidae	Coleoptera
	M. discolor Boheman	Curculionidae	Coleoptera
	M. laetivirens Mshll.	Curculionidae	Coleoptera
	M. maculosus Desbr.	Curculionidae	Coleoptera
	M. sabulosus Mshll.	Curculionidae	Coleoptera
	M. transmarinus Hbst.	Curculionidae	Coleoptera
Stem weevil	*Pempherulus affinis* Fst.	Curculionidae	Coleoptera
	Tanymecus hispidus Mshll.	Curculionidae	Coleoptera
	T. indicus Fst.	Curculionidae	Coleoptera
	T. princeps Fst.	Curuclionidae	Coleoptera
	T. sciurus Oliv.	Curculionidae	Coleoptera

Hibiscus cannabinus (Gogu or Mesta)

Red Cotton bug	*Dysdercus cingulatus* (Fb.)	Pyrrhocoridae	Hemiptera
Green plant bug	*Nezara viridula* Linn.	Pentatomidae	Hemiptera
Cotton jassid	*Empoasca devastans* Distant	Cicadellidae	Hemiptera
Mealy bug	*Maconellicoccus hirsutus* (Green)	Pseudococcidae	Hemiptera
Scale insect	*Pinnaspis strachani* (Cooly)	Diaspididae	Hemiptera
Cotton pink bollowrm	*Pectinophora gossypiella* Saund.	Gelechiidae	Lepidoptera
Green semilooper	*Anomis flava* F.	Noctuidae	Lepidoptera
Cotton spotted bollwsorm	*Earias insulana* Boisd.	Noctuidae	Lepidoptera
Cotton spiny bollworm	*Earias vittella* (F.)	Noctuidae	Lepidoptera
Tussock caterpillar	*Porthesia scintillans* Wlk.	Lymantriidae	Lepidoptera
Stem borer	*Agrilus acutus* Thunb.	Buprestidae	Coleoptera
Flower beetle	*Mylabris pustulata* Th.	Meloidae	Coleoptera
Flea beetle	*Podagrica bowringi* Baly.	Alticidae	Coleoptera
	P. madurensis J.	Alticidae	Coleoptera
Stored seed borer	*Spermophagus tessellatus* Mots.	Bruchidae	Coleoptera
Stem weevil	*Alcidodes affaber* F.	Curuculionidae	Coleoptera
Leaf weevil	*Dereodus mastos* Hb.	Curuculionidae	Coleoptera
	Crabro orientalis Cameron	Apidae	Hymenoptera

Hibiscus sabdariffa (ROSELLE)

Mealy bug	*Maconellicoccus hirsutus* (Green)	Pseudococcidae	Hemiptera
Hard scale	*Cerococcus hibisci* Green	Coccidae	Hemiptera
Cotton spotted bollworm	*E. vittella* (F.)	Coccidae	Hemiptera
Lygaeid bug	*Spilostethus pandurus* (Scop.)	Lygaeidae	Hemiptera
Tussock caterpillar	*Porthesia scintillans* Wlk.	Lymantriidae	Hemiptera
Sepentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Stem borer	*Agrilus acutus* Thunb.	Buprestidae	Coleoptera
Seed bruchid	*Spermophagus pygopubens* P.	Bruchidae	Coleoptera

OIL SEEDS

Arachis hypogaea (GROUNDNUT)

Surface grasshopper	*Atractomorpha crenulata* Fab.	Acrididae	Orthoptera
Surface grasshopper	*Chrotogonus brachypterus* Blanch	Acrididae	Orthoptera
	C. saussurei B.	Acrididae	Orthoptera
	Cyrtacanthacris tatarica (L.)	Acrididae	Orthoptera
White ant	*Odontotermes obesus* Ramb.	Termitidae	Isoptera
Groundnut earwig	*Euborellia annulipes* Lucas	Forficulidae	Dermaptera
Earwig	*Labidura bengalensis*	Forficulidae	Dermaptera
White-backed planthopper	*Sogatella furcifera* (Harnvath)	Delphacidae	Hemiptera
Plant hopper	*Toya propinqua* Fieber	Delphacidae	Hemiptera
Aphid	*Aphis craccivora* Koch.	Aphididae	Hemiptera
Seed bug	*Elasmolomus sordidus* Fb.	Lygaeidae	Hemiptera
Cotton whitefly	*Bemisia tabaci (Gennadius)*	Aleyrodidae	Hemiptera
Jassid	*Empoasca kerii* Pruthi	Cicadellidae	Hemiptera

Root nodule mealy bug	*Dysmicoccus breviceps* (Ckll.)	Pseudococcidae	Hemiptera
Red cotton bug	*Dysdercus cingulatus* (Fb.)	Pyrrhocoridae	Hemiptera
Green stink bug	*Nezara viridula* (L.)	Pentatomidae	Hemiptera
Coreid bug	*Cletus signatus* (Walk.)	Coreidae	Hemiptera
Sugarcane pyrilla	*Pyrilla perpusilla* (Walk.)	Lophopidae	Hemiptera
Thrips	*Caliothrips indicus* (Bagnall)	Thripidae	Thysanoptera
	Frankliniella schultzei Trybom	Thripidae	Thysanoptera
	Retithrips syriacus (Mayet)	Thripidae	Thysanoptera
	Megalurothrips usitatus (Bagnall)	Thripidae	Thysanoptera
	Scirtothrips dorsalis Hood	Thripidae	Thysanoptera
Leaf miner	*Aproaerema modicella* Deventer	Gelechiidae	Lepidoptera
	Cadra cautella (Wlk.)	Pyralidae	Lepidoptera
Rice meal moth	*Corcyra cephalonica* St.	Pyralidae	Lepidoptera
	Amsacta albistriga Wlk.	Arctiidae	Lepidoptera
	A. moorei Butl.	Arctiidae	Lepidoptera
	Spilarctia obliqua (Wlk.)	Arctiidae	Lepidoptera
	Chrysodeixis chalcites Esp.	Noctuidae	Lepidoptera
	C. eriosoma (D.)	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
	Plusia signata F.	Noctuidae	Lepidoptera
Hairy caterpillar	*Cricula trifenestrata* H.	Saturniidae	Lepidoptera
Flower beetle	*Oxycetonia versicolor* Fb.	Cetoniidae	Coleoptera
Flea beetle	*Phyllotreta chotanica* Duv.	Alticidae	Coleoptera
White grub	*Anomala bengalensis* Blach.	Rutelidae	Coleoptera
	Holotrichia consanguinea Blanch.	Melolonthidae	Coleoptera
	H. insularis Brenske	Melolonthidae	Coleoptera
	Lachnosterna fissa	Melolonthidae	Coleoptera
Khapra beetle	*Trogoderma granarium* (Everts)	Dermestidae	Coleoptera
Groundnut ver poochi	*Sphenoptera perotetti* Guerin	Buprestidae	Coleoptera
Lesser grain borer	*Rhyzopertha dominica* (Fabr.)	Bostrychidae	Coleoptera
"Cadella" beetle	*Tenebroides mauritanicus* Linn.	Ostomatidae	Coleoptera
Red-legged ham beetle	*Becrobia rufipes* De Geer	Cleridae	Coleoptera
	Carpophilus dimidiatus E.	Nitidulidae	Coleoptera
Flat grain beetle	*Laemophaleus pusillus* Oliv.	Cucujidae	Coleoptera
	Alphitobius laevigatus (Fabr.)	Tenebrionidae	Coleoptera
Dusky brown beettel	*Gonocephalum* sp.	Tenebrionidae	Coleoptera
Red flour beetle	*Tribolium castaneum* Hbst.	Tenebrionidae	Coleoptera
Saw toothed borer	*Oryzaephilus surinamensis* Linn.	Silvanidae	Coleoptera
Flower beetle	*Mylabris balteata*	Meloidae	Coleoptera
	M. pustulata (Thunb.)	Meloidae	Coleoptera
Leaf weevil	*Myllocerus viridanus* F.	Curuculionidae	Coleoptera
Army ant	*Dorylus orientalis* Westwood	Formicidae	Hymenoptera

Brassica campestris (RAPE AND MUSTARD)

Cabbage aphid	*Brevicoryne brassicae* (Linn.)	Aphididae	Hemiptera
Plant lice	*Lipaphis erysimi* (Kalt.)	Aphididae	Hemiptera
	Myzus periscae S.	Aphididae	Hemiptera

Cotton white fly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	Hemiptera
Painted plant bug	*Bagrada cruciferarum* F.	Pentatomidae	Hemiptera
Flower thrips	*Aeolothrips collaris* Pr.	Aeolothripidae	Thysanoptera
	Thrips flavus Sch.	Thripidae	Thysanoptera
Diamond back moth	*Plutella xylostella* (L.)	Plutellidae	Lepidoptera
Cruciferous leaf weeber	*Crocidolomia pavonana* F.	Pyralidae	Lepidoptera
Cabbage borer	*Hellula undalis* Fb.	Pyralidae	Lepidoptera
Cabbage butterfly	*Pieris brassicae* Lina.	Pieridae	Lepidoptera
Bihar hairy caterpillar	*Spilarctia obliqua* (Wlk.)	Arctiidae	Lepidoptera
Greasy cutworm	*Agrotis ipsilon* (Hufn.)	Noctuidae	Lepidoptera
Pea leaf miner	*Chromatomyia horticola* (Gour.)	Agromyzidae	Diptera
Mustard sawfly	*Athalia proxima* (Klug.)	Tenthredinidae	Hymenoptera
Flea beetle	*Phyllotreta cruciferae* G.	Alticidae	Coleoptera

Carthamus tinctorius (SAFFLOWER)

Wingless grasshopper	*Neorthacris simulans* B.	Acrididae	Orthoptera
Green leafhopper	*Empoasca* sp.	Cicadellidae	Hemiptera
White leafhopper	*Typhlocyba* sp.	Cicadellidae	Hemiptera
Cotton aphid	*Aphis gossypii* G.	Aphididae	Hemiptera
Safflower aphid	*Uroleucon carthami* Theo.	Aphididae	Hemiptera
Cotton white fly	*Bemisia tabaci* (Genn.)	Aleyrodidae	Hemiptera
White-tailed mealy bug	*Ferrisia virgata* (Ckll.)	Pseudococcidae	Hemiptera
Lacewing bug	*Monanthia globulifera* W.	Tingidae	Hemiptera
	Spilostethus hospes F.	Lygaeidae	Hemiptera
	S. militaris F.	Lygaeidae	Hemiptera
	Dolycoris indicus Stal.	Pentatomidae	Hemiptera
	Nezara graminea Fabr.	Pentatomidae	Hemiptera
	Frankliniella schultzei Priesner	Thripidae	Thysanoptera
Compositae thrips	*Microcephalothrips abdominalis* (Craw.)	Thripidae	Thysanoptera
	Thrips carthami Shumsher	Thripidae	Thysanoptera
	T. hawaiiensis (Morgan)	Thripidae	Thysanoptera
Safflower caterpillar	*Condica capensis* Guen.	Noctuidae	Lepidoptera
Safflower semilooper	*Eublemma rivula* Moore	Noctuidae	Lepidoptera
	Helicoverpa armigera Hb.	Noctuidae	Lepidoptera
	H. peltigera Sch.	Noctuidae	Lepidoptera
	Spodoptera exigua (Hb.)	Noctuidae	Lepidoptera
Green semilooper	*Thysanoplusia orichalcea* Hb.	Noctuidae	Lepidoptera
Cabbage semilooper	*Trichopulsia ni* Hb.	Noctuidae	Lepidoptera
Safflower fly	*Acanthiophilus helianthi* Rossi	Tephritidae	Diptera
Leaf miner	*Chromatomyia horticola* (Gour.)	Agromyzidae	Diptera
Serpentine leaf miner	*Liriomyza trifolli* (Burgess)	Agromyzidae	Diptera
	Melanagromyza obtusa (Malloch)	Agromyzidae	Diptera
Surface weevil	*Tanymecus indicus* Fst.	Curculionidae	Coleoptera

Cocos nucifera (COCONUT)

Coffee grashopper	*Aularches miliaris* L.	Acrididae	Orthoptera

Bombay locust	*Patanga succincta* L.	Acrididae	Orthoptera
Termite	*Odontotermes obesus* Ramb	Termitidae	Isoptera
Coconut aphid	*Cerataphis brasiliensis*	Aphididae	Hemiptera
Rusty plum aphid	*Hysteroneura setariae* (Thomas)	Aphididae	Hemiptera
Mealy bug	*Dysmicoccus breviceps* (Ckll.)	Pseudococcidae	Hemiptera
Mealy bug	*Pseudococcus coccotis* Mask.	Pseudococcidae	Hemiptera
	P. longispinus T.	Pseudococcidae	Hemiptera
Scale instct	*Ceroplastes actiniformis* G.	Coccidae	Hemiptera
	Coccus hesperidum (Linn.)	Coccidae	Hemiptera
	Lacanium acutissimum Gr.	Coccidae	Hemiptera
	Vinsonia stellifera W.	Coccidae	Hemiptera
Scale insect	*Aonidiella orientalis* (Newst.)	Diaspididae	Hemiptera
Coconut scale	*Aspidiotus destructor* S.	Diaspididae	Hemiptera
	Chrysomphalus ficus A.	Diaspididae	Hemiptera
	Pinnaspis aspidistrae Sign.	Diaspididae	Hemiptera
Lacewing bug	*Stephantis typica* Dist.	Tingidae	Hemiptera
Flower thrips	*Haplothrips ceylonicus* Schmutz	Phloeothripidae	Thysanoptera
Inflorescence caterpillar	*Batrachedra arenosella* W.	Cosmopterygidae	Lepidoptera
	Coconympha iridarcha M.	Gelechiidae	Lepidoptera
Black-headed caterpillar	*Opisina arenosella* (Wlk.)	Oecophoridae	Lepidoptera
Bag worm	*Manatha albipes*	Psychidae	Lepidoptera
	Contheyla rotunda H.	Limacodiidae	Lepidoptera
Castor slug caterpillar	*Lakoia lepida* C.	Limacodiidae	Lepidoptera
	Macroplectra nararia M.	Limacodiidae	Lepidoptera
Defoliator	*Phalera* sp.	Drepanidae	Lepidoptera
Coconut skipper	*Gangara thyrsis* M.	Hesperiidae	Lepidoptera
	Suastus gremius F.	Hesperiidae	Lepidoptera
Inflorescence caterpillar	*Turnaca acuta* W.	Notodontidae	Lepidoptera
Nut borer	*Cyclodes omma*	Noctuidae	Lepidoptera
	Dorylus orientalis Westw.	Formicidae	Hymenoptera
Red ant	*Oecophylla smaragdina* F.	Formicidae	Hymenoptera
Rhinoceros beetle	*Oryctes rhinoceros* Linn.	Dynastidae	Coleoptera
	Xylotrupes gideon L.	Dynastidae	Coleoptera
White grub	*Leucophalis coneophora* Burm.	Melolonthidae	Coleoptera
	Adoretus lasiopygus Burn.	Rutelidae	Coleoptera
	A. lithobius	Rutelidae	Coleoptera
Leaf beetle	*Callispa* sp. nr. *minima* Gestro	Hispidae	Coleoptera
Inflorescence weevil	*Amorphoidea* sp.	Curculionidae	Coleoptera
Leaf weevil	*Dereodus sparsus* B.	Curculionidae	Coleoptera
Stem weevil	*Diocalandra stigmaticollis* G.	Curculionidae	Coleoptera
Red palm weevil	*Rhynchophorus ferrugineus* F.	Curculionidae	Coleoptera
Shot-hole borer	*Xyleborus parvulus* E.	Scolytidae	Coleoptera

***Helianthus annuus* (SUNFLOWER)**

Surface grasshopper	*Chrotogonus oxypterus* (B.)	Pyrgomorphidae	Orthoptera
'Ak' grasshopper	*Poekilocerus pictus* F.	Acrididae	Orthoptera

Green grasshopper	*Atractomorpha crenulata crenulata* F.	Acrididae	Orthoptera
	A. obscura	Acrididae	Orthoptera
Wingless grasshopper	*Neorthacris simulans* B.	Acrididae	Orthoptera
	Cyrtacanthacris ranacea	Acrididae	Orthoptera
Cotton leafhopper	*Empoasca devastans* Distaant	Cicadellidae	Hemiptera
Brown leafhopper	*Cicadilina zeal* China	Cicadellidae	Hemiptera
Cottom whitefly	*Bemisia tabaci* (Genn.)	Aleyrodidae	Hemiptera
Bean aphid	*Aphis craccivora* Koch.	Aphididae	Hemiptera
Cotton aphid	*A. gossypii* G.	Aphididae	Hemiptera
Peach leaf curl aphis	*Brachycaudus helichrysi* Kalt.	Aphididae	Hemiptera
Cowbug	*Leptocentrus substitutus* Wlk.	Membracidae	Hemiptera
Cowbug	*Oxyrhachis tarandus* Fab.	Membracidae	Hemiptera
Lacewing bug	*Cadmilos retiarius* Dist.	Tingidae	Hemiptera
	Galeatus scrophilus Saunders	Tingidae	Hemiptera
Rice earhead bug	*Leptoorisa acuta* T.	Alydidae	Hemiptera
	Clavigralla gibbosa Spin.	Coreidae	Hemiptera
Groundaut pod bug	*Elasmolomus sordidus* Fb.	Lygaeidae	Hemiptera
Green plant bug	*Nezara viridula* Linn.	Pentatomidae	Hemiptera
Yellow plant bug	*Dolycoris indicus* S.	Pentatomidae	Hemiptera
Brown bug	*Dalpada pillicornis* Stoll.	Pentatomidae	Hemiptera
	Eysarcocoris guttiger Th.	Pentatomidae	Hemiptera
	E. porrectus B.	Pentatomidae	Hemiptera
Yellow flower thrips	*Frankliniella dampfii* Priesner	Thripidae	Thysanoptera
	F. schultzei Trybom	Thripidae	Thysanoptera
	Megalurothrips usitatus Bagnall	Thripidae	Thysanoptera
Leaf thrips	*Scritothrips dorsalis* Hood	Thripidae	Thysanoptera
	Thrips hawaiiensis Karny	Thripidae	Thysanoptera
	Haplothrips ganglbaueri Schmutz	Phlaeothripidae	Thysanoptera
Black flower thrips	*H. nigricornis*	Phlaeothripidae	Thysanoptera
Black hairy caterpillar	*Pericallia ricini* F.	Arctiidae	Lepidoptera
Bihar hairy caterpillar	*Spilarctia obliqua* (Walk.)	Arctiidae	Lepidoptera
Head caterpillar	*Stathmopoda theoris* Meyr.	Heliodinidae	Lepidoptera
Castor capsule borer	*Conogethes punctiferalis* (Guen.)	Pyralidae	Lepidoptera
Safflower caterpillar	*Condica capensis* G.	Noctuidae	Lepidoptera
Seed borer	*Eublemma silicula* Swinhoe	Noctuidae	Lepidoptera
Gram caterpillar	*Helicoverpa armigera* (Hb.)	Noctuidae	Lepidoptera
Green semilooper	*Plusia signata* F.	Noctuidae	Lepidoptera
Tobacco caterpillar	*Spodoptera litura* (F.)	Noctuidae	Lepidoptera
Green semilooper	*Thysanoplusia orichalcea* F.	Noctuidae	Lepidoptera
Cabbage semilooper	*Trichoplusia ni* (Hb.)	Noctuidae	Lepidoptera
Hairy caterpillar	*Porthesia xanthorrhoea* (Koll.)	Lymantriidae	Lepidoptera
Fruitfly	*Craspedoxantha octopunctata* B.	Tephritidae	Diptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Ground beetle	*Gonocephalum* sp.nr. *planatum* Wlk.	Tenebrionidae	Coleoptera

Sap beetle	*Carpophilus* sp.	Nitidulidae	Coleoptera
	Pachnephorus impressus Rosen.	Eumolpidae	Coleoptera
Brown bruchid	*Caryedon serratus*	Bruchidae	Coleoptera
Sawtoothed beetle	*Oryzaephilus mercator* Fauver	Silvanidae	Coleoptera
Stored pest	*Tribolium castaneum* Herbst.	Tenebrionidae	Coleoptera
Stored pest	*T. confusum* J. du Val.	Tenebrionidae	Coleoptera
Chafer beetle	*Oxycetonia versicolor* F.	Cetoniidae	Coleoptera
Cotton seedling weevil	*Atactogaster finitimus* H.	Curculionidae	Coleoptera
Ash weevil	*Myllocerus discolor* F.	Curculionidae	Coleoptera
	M. maculasus Desb.	Curculionidae	Coleoptera
	M. viridanus F.	Curculionidae	Coleoptera
	Ptochus ovulum	Curculionidae	Coleoptera

***Linum usitatisimum* (LINSEED)**

Grasshopper	*Acrida exaltata* Walk.	Acrididae	Orthoptera
Surface grasshopper	*Chrotogonus trachypterus* Blch.	Pyrgomorphidae	Orthoptera
Termite	*Odontotermes obesus* R.	Termitidae	Isoptera
Cotton whitefly	*Besmisia tabaci* (Genn.)	Aleyrodidae	Hemiptera
Jassid	*Empoasca kerri* Pruthi	Cicadellidae	Hemiptera
Bean aphid	*Aphis craccivora* Koch.	Aphididae	Hemiptera
Green aphid	*Myzus persicae* Sulz.	Aphididae	Hemiptera
Green bug	*Creontiades pallidifer* Wlk.	Miridae	Hemiptera
Red cotton bug	*Dysdercus cingulatus* L.	Pyrrhocoridae	Hemiptera
Painted bug	*Bagrada cruciferarum* Kirk.	Pentatomidae	Hemiptera
	Dolycoris indicus Stal.	Pentatomidae	Hemiptera
Green bug	*Nezara viridula* Linn.	Pentatomidae	Hemiptera
Thrips	*Caliothrips indicus* Bagnall	Thripidae	Thysanoptera
Bihar hairy caterpillar	*Spilarctia obliqua* Wlk.	Arctiidae	Lepidoptera
	Cadra cautella (Wlk.)	Pyralidae	Lepidoptera
	Corcyra cephalonica S.	Pyralidae	Lepidoptera
Cabbage butterfly	*Pieris brassicae* L.	Pieridae	Lepidoptera
Cutworm	*Agrotis flammatra* Schiff.	Noctuidae	Lepidoptera
Cutworm	*Agrotis ipsilon* (Hufn.)	Noctuidae	Lepidoptera
Safflower caterpillar	*Condica capensis* (Guen.)	Noctuidae	Lepidoptera
Leaf caterpillar	*Grammodes stolida* F.	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
	Laphygma exigua Hb.	Noctuidae	Lepidoptera
Army worm	*Mythimna loreyi* D.	Noctuidae	Lepidoptera
Tobacco caterpillar	*Spodoptera litura* Fb.	Noctuidae	Lepidoptera
Green semilooper	*Thysanoplusia orichalcea* F.	Noctuidae	Lepidoptera
Hairy caterpillar	*Euproctis icilia* Stoll.	Lymantriidae	Lepidoptera
Tussock caterpillar	*Olene mendosa* Hb.	Lymantriidae	Lepidoptera
	Porthesia scintillans W.	Lymantriidae	Lepidoptera
Blossom midge	*Dasineura lini* Barnes	Cecidomyiidae	Diptera
Pea leaf miner	*Chromatomyia horticola* (Gour.)	Agromyzidae	Diptera
Red pumpkin beetle	*Raphidopalpa foveicollis* Lucas	Galeuricidae	Coleoptera

Weevil	*Myllocerus cetulifer* Desb.	Curculionidae	Coleoptera

Ricinus communis (CASTOR)

Rice smaller grasshopper	*Oxya nitidula* Willemse	Acrididae	Orthoptera
'AK' grasshopper	*Poekilocerus pictus* F.	Acrididae	Orthoptera
Castor leaf hopper	*Empoasca flavescens* F.	Cicadellidae	Hemiptera
Castor whitefly	*Trialeurodes ricini* (Misra)	Aleyrodidae	Hemiptera
Scale insect	*Aonidiella andersoni* (Laing.)	Diaspididae	Hemiptera
	A. orientalis Newst.	Diaspididae	Hemiptera
	Aspidiotus destructor Sign.	Diaspididae	Hemiptera
	Parasaissetia nigra (Niet.)	Coccidae	Hemiptera
	Nezara viridula Linn.	Pentatomidae	Hemiptera
Thrips	*Astrothrips parvilimbus* St. & Mit.	Thripidae	Thysanoptera
	Ayyaria chaetophora Karny	Thripidae	Thysanoptera
Inflorescence thrips	*Craspedothrips minor* (Bagnall)	Thripidae	Thysanoptera
	Retithrips syriacus (Mayet)	Thripidae	Thysanoptera
Thrips	*Scirtothrips dorsalis* Hood	Thripidae	Thysanoptera
	Zaniothrips ricini Bhatti	Thripidae	Thysanoptera
Bagworm	*Eumeta crameri* (Westw.)	Psychidae	Lepidoptera
	Trabala vishnou L.	Lasiocampidae	Lepidoptera
	Altha nivea W.	Limacodiidae	Lepidoptera
Castor slug	*Latoia lepida* C.	Limacodiidae	Lepidoptera
Humped slug	*Spatulicraspeda castaneiceps* Hmpsn.	Limacodiidae	Lepidoptera
	Thosea cana Walk.	Limacodiidae	Lepidoptera
	T. triparita Moore	Limacodiidae	Lepidoptera
Capsule eucosmid	*Lobesia aelopa* H.	Eucosmidae	Lepidoptera
Webworm	*Cryptoblabes angustipennella* Hmpsn.	Pyralidae	Lepidoptera
Shoot and capsule borer	*Conogethes punctiferalis* Guen.	Pyralidae	Lepidoptera
Capsule pyralid	*Myelosis pectinicornella* H.	Pyralidae	Lepidoptera
Eri silkworm	*Samia cynthia ricini* Boisduval	Saturniidae	Lepidoptera
Spiny caterpillar	*Ariadne merione merione* C.	Nymphalidae	Lepidoptera
Looper caterpillar	*Hyposidra talaca* Wlk.	Geometridae	Lepidoptera
	Amsacta albistriga Wlk.	Arctiidae	Lepidoptera
	A. moorei Butl.	Arctiidae	Lepidoptera
	Pericallia ricini F.	Arctiidae	Lepidoptera
	Spilarctia obliqua (Wlk.)	Arctiidae	Lepidoptera
Castor semilooper	*Achaea janata* Linn.	Noctuidae	Lepidoptera
	A. melicerta Linn.	Noctuidae	Lepidoptera
	Eublemma silicula Swinhoe	Noctuidae	Lepidoptera
	Helicoverpa armigera Hb.	Noctuidae	Lepidoptera
	Paralellia algira L.	Noctuidae	Lepidoptera
	P. stuposa F.	Noctuidae	Lepidoptera
	Spodoptera litura (F.)	Noctuidae	Lepidoptera
Hairy caterpillar	*Euproctis fraterna* M.	Lymantriidae	Lepidoptera
	E. icilia Stoll.	Lymantriidae	Lepidoptera

	E. limbata Butler	Lymantriidae	Lepidoptera
	E. lunata (Wlk.)	Lymantriidae	Lepidoptera
	E. subnotata Wlk.	Lymantriidae	Lepidoptera
Tussock caterpillar	*Olene mendosa* Hb.	Lymantriidae	Lepidoptera
	Notolophus posticus Wlk.	Lymantriidae	Lepidoptera
	Porthesia scintillans W.	Lymantriidae	Lepidoptera
Castor gall ridge	*Asphondylia ricini* Mani	Cecidomyiidae	Diptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
White grub	*Holotrichia consanguinea* Blanch.	Melolonthidae	Coleoptera
Flea beetle	*Hermacophaga ruficollis* L.	Alticidae	Coleoptera
Leaf weevil	*Myllocerus maculosus* Desbr.	Curculionidae	Coleoptera
	M. viridanus F.	Curculionidae	Coleoptera
Shot-hole borer	*Euwallacea fornicatus* E.	Scolytidae	Coleoptera

***Sesamum indicum* (GINGELLY)**

Surface grasshopper	*Chrotogonus trachypterus* (Blanch)	Pyrgomorphidae	Orthoptera
	Pyrgomorpha conicadeserti Bei-Bienko	Pyrgomorphidae	Orthoptera
Termites	*Microtermes* sp.	Termitidae	Isoptera
Cowpea green leafhopper	*Empoasca terminalis* Dist.	Cicadellidae	Hemiptera
	Empoascarana maculifrons (M.)	Cicadellidae	Hemiptera
	Exitianus sp.	Cicadellidae	Hemiptera
Brinjal leafhopper	*Hishimonus phycitis* (Dist.)	Cicadellidae	Hemiptera
Sesamum leafhopper	*Orosius albicinctus* Dist.	Cicadellidae	Hemiptera
Aphid	*Aphis gossypii* G.	Aphididae	Hemiptera
Peach green aphid	*Myzus persicae* (Sulz.)	Aphididae	Hemiptera
Cotton whitefly	*Bemisia tabaci* (Genn.)	Aleyrodidae	Hemiptera
	Campyloma sp.	Miridae	Hemiptera
	Creontiades pallidifer W.	Miridae	Hemiptera
	Cryptopeltis tenuis L.	Miridae	Hemiptera
	Ragmus niorosus Ballard	Miridae	Hemiptera
	Elasmolomus sordidus Fab.	Lygaeidae	Hemiptera
	Spilostethus militaris F.	Lygaeidae	Hemiptera
	S. pandurus (Scop.)	Lygaeidae	Hemiptera
	Nysius inconspicuous D.	Lygaeidae	Hemiptera
Tur pod bug	*Clavigralla gibbosa* Spin.	Coreidae	Hemiptera
	Dysdercus cingulatus (Fab.)	Pyrrhocoridae	Hemiptera
	Adria parvula Dall.	Pentatomidae	Hemiptera
	Bagrada cruciferarum (Kirk)	Pentatomidae	Hemiptera
	Coridius janus (F.)	Pentatomidae	Hemiptera
	Dolycoris indicus S.	Pentatomidae	Hemiptera
	Eysarcoris ventralis W.	Pentatomidae	Hemiptera
	Nezara viridula Linn.	Pentatomidae	Hemiptera
Flower thrips	*Frankliniella schultzei* Trybom	Thripidae	Thysanoptera
	Ramaswamiahiella subnudula Karny	Thripidae	Thysanoptera
	Scirtothrips dorsalis Hood	Thripidae	Thysanoptera

	T. hawaiiensis (Morgan)	Thripidae	Thysanoptera
	T. palmi Karny	Thripidae	Thysanoptera
	T. tabaci Lind	Thripidae	Thysanoptera
Leaf webber	*Antigastra catalaunalis* (Dup.)	Pyralidae	Lepidoptera
	Cadra cautella (Wlk)	Pyralidae	Lepidoptera
	Corcyra cephalonica St.	Pyralidae	Lepidoptera
	Amsacta albistriga Wlk.	Arctiidae	Lepidoptera
Black hairy caterpillar	*A. lactinea* (C.)	Arctiidae	Lepidoptera
	A. moorei Butl.	Arctiidae	Lepidoptera
Woolly bear	*Pericallia ricini* F.	Arctiidae	Lepidoptera
Bihar hairy caterpillar	*Spilarctia obliqua* (Wlk.)	Arctiidae	Lepidoptera
Sphingid caterpillar	*Acherontia lachesis*	Sphingidae	Lepidoptera
	A. styx Westw.	Sphingidae	Lepidoptera
	Hippotion echeclus (Boisd)	Sphingidae	Lepidoptera
Gram caterpillar	*Helicoverpa armigera* (Hb.)	Noctuidae	Lepidoptera
Lucerne caterpillar	*Spodoptera exigua* (Hub.)	Noctuidae	Lepidoptera
Tobacco caterpillar	*Spodoptera litura* (Fab.)	Noctuidae	Lepidoptera
Cabbage semilooper	*Thysanoplusia orichalcea* (Fab.)	Noctuidae	Lepidoptera
Tussock caterpillar	*Porthesia scintillans* W.	Lymantriidae	Lepidoptera
Sesamum fly	*Gitonides perspicax* Knab	Drosophilidae	Diptera
Pea leaf miner	*Chromatomyia horticola* (Gour)	Agromyzidae	Diptera
Stem fly	*Melanagromyza azawii* Spencer	Agromyzidae	Diptera
Shoot borer	*M. obtusa* Malloch	Agromyzidae	Diptera
Stem maggot	*Chyliza* sp.	Psilidae	Diptera
Sesamum gall fly	*Asphondylia sesami* Felt.	Cecidomyiidae	Diptera
Linseed gall fly	*Dasineura lini* Barnes	Cecidomyiidae	Diptera
Blossom midge	*D. sesami* Grover & Prasad	Cecidomyiidae	Diptera
Pod wasp	*Eurytoma* sp.	Eurytomidae	Hymenoptera
Ant	*Monomorium destructor* Jordon	Formicidae	Hymenoptera
Khapra beetle	*Trogoderma granarium* (Everts)	Dermestidae	Coleoptera
Flower beetle	*Oxycetonia albopunctata* Fb.	Cetoniidae	Coleoptera
Palas white grub	*Holotrichia serrata* Fab.	Melolonthidae	Coleoptera
Flower beetle	*Serica insanabilis* Brens.	Scarabaeidae	Coleoptera
Saw-toothed borer	*Oryzaephilus surinamensis* Linn.	Silvanidae	Coleoptera
Blister beetle	*Mylabris pustulata* (Thunb.)	Meloidae	Coleoptera
	Zanitomorpha melanoptera Fairm	Meloidae	Coleoptera
Red pumpkin beetle	*Aulacophora foveicollis* (Lucas)	Galeuricidae	Coleoptera
Wheat flea beetle	*Chaetocnema basalis* Baly.	Alticidae	Coleoptera
	Pachnephorus bistriatus Muls.	Eumolpidae	Coleoptera
Red flour beetle	*Tribolium castaneum* Hbst.	Tenebrionidae	Coleoptera
Stem boring beetle	*Oberea* sp.	Ceramybycidae	Coleoptera
Black weevil	*Cyertozenia dispar* Mshll.	Curculionidae	Coleoptera
	C. coquata Mshll	Curculionidae	Coleoptera
	Episomus lacerta Fab.	Curculionidae	Coleoptera

PULSES

Cajanus cajan (PIGEON PEA OR REDGRAM)

Grasshopper	*Aiolopus* sp.	Acrididae	Orthoptera
	Atractomorpha crenulata (Fabr.)	Acrididae	Orthoptera
	Cyrtacanthacris tatarica (L.)	Acrididae	Orthoptera
	Oedalens abruptus (thunb)	Acrididae	Orthoptera
	Allodape alicus (Brun.)	Tettigoniidae	Orthoptera
White ant	*Odontotermes pallidens* H.	Termitidae	Isoptera
Cow bug	*Coccosterphus obscurus* Dist.	Membracidae	Hemiptera
	Gargara flavolineata Dist.	Membracidae	Hemiptera
	G. mixa Buck.	Membracidae	Hemiptera
	Leptocentrus obliquus W.	Membracidae	Hemiptera
	Otinotus oneratus W.	Membracidae	Hemiptera
Cow bug	*Oxyrhachis tarandus* F.	Membracidae	Hemiptera
	Tricentrus bicolor Dist.	Membracidae	Hemiptera
Spittle bug	*Ptyleus nebulosus* Fabr.	Cercopiidae	Hemiptera
	Scipina horrida Stal.	Cercopiidae	Hemiptera
	Cofana spectra (Dist.)	Cicadellidae	Hemiptera
Leaf hopper	*Empoasca binotata*	Cicadellidae	Hemiptera
	E. kerii Pruthi	Cicadellidae	Hemiptera
	Eutettix phycitis Dist.	Cicadellidae	Hemiptera
	Typhlocyba sp.	Cicadellidae	Hemiptera
	Eurybrachys tomentosa Fb.	Eurybrachidae	Hemiptera
Plant lice	*Aphis craccivora* Koch.	Aphididae	Hemiptera
	Myzus persicae (Sulzer)	Aphididae	Hemiptera
	Drosicha stebbingi Gr.	Margarodidae	Hemiptera
	Margarodes niger Gr.	Margarodidae	Hemiptera
	M. papillosus Gr.	Margarodidae	Hemiptera
Lac insect	*Kerria lacca* (Kerr.)	Kerridae	Hemiptera
	Ceroplastodes cajani Mask.	Coccidae	Hemiptera
	Coccus hesperidum L.	Coccidae	Hemiptera
	C. longulum (Dougl.)	Coccidae	Hemiptera
	Saissetia coffeae (Walker)	Coccidae	Hemiptera
	S. oleae (Olivier)	Coccidae	Hemiptera
	Centrococcus insolitus (Gr.)	Pseudococcidae	Hemiptera
	Dysmicocus breviceps (Ckll.)	Pseudococcidae	Hemiptera
	Ferrisia virgata C.	Pseudococcidae	Hemiptera
	Nipaecoccus cajani (Newst.)	Pseudococcidae	Hemiptera
	N. vastator (Maskell)	Pseudococcidae	Hemiptera
	Planococcus citri Riso.	Pseudococcidae	Hemiptera
	Rastrococcus sp.	Pseudococcidae	Hemiptera
	Creontades stramineus (Walk.)	Miridae	Hemiptera
Gram pod bug	*Clavigralla gibbosa* S.	Coreidae	Hemiptera
	C. horrens D.	Coreidae	Hemiptera
	Cletomorpha hastata Fabr.	Coreidae	Hemiptera
	Cletus bipunctatus Westw.	Coreidae	Hemiptera

	Homoeocerus sp.	Coreidae	Hemiptera
	Riptortus fuscus F.	Coreidae	Hemiptera
	R. linearis F.	Coreidae	Hemiptera
	R. pedestris F.	Coreidae	Hemiptera
	Spilostethus hospes (Fabr.)	Lygaeidae	Hemiptera
	Coptosoma cribraria F.	Plataspididae	Hemiptera
	C. nazirae At.	Plataspididae	Hemiptera
	C. siamicum Walk.	Plataspididae	Hemiptera
	Chrysocoris purpureus Westw.	Scutelleridae	Hemiptera
	C. stolli Wolff.	Scutelleridae	Hemiptera
	Aspongopus janus Fabr.	Pentatomidae	Hemiptera
	Cyclopelta siccifolia Westw.	Pentatomidae	Hemiptera
	Dolycoris indicus Stal.	Pentatomidae	Hemiptera
	Nezara viridula Linn.	Pentatomidae	Hemiptera
Thrips	*Megalurothrips distalis* Karny	Thripidae	Thysanoptera
Flower thrips	*M. usitatus* (Bagnall)	Thripidae	Thysanoptera
	Megalurothrips nigricornis (Priesner)	Thripidae	Thysanoptera
	Thrips hawaiiensis (Morgan)	Thripidae	Thysanoptera
Leaf webber	*Anarsia ephippias* Meyr.	Gelechiidae	Lepidoptera
Groundnut leaf miner	*Aproaerema modicella* Dev.	Gelechiidae	Lepidoptera
Leaf roller	*Gracillaria soyella* D.	Gracillariidae	Lepidoptera
	Thosea aperiens Wlk.	Limacodiidae	Lepidoptera
Leaf roller	*Cydia (= Eucosma) critica* Meyr.	Eucosmidae	Lepidoptera
	E. melanaula Mer.	Eucosmidae	Lepidoptera
	Archips micacaeana St.	Tortricidae	Lepidoptera
Pod borer	*Pylaetis mimosae* St.	Tineidae	Lepidoptera
Pod borer	*Etiella zinckenella* Treit.	Pyralidae	Lepidoptera
Leaf caterpillar	*Glyphodes bivitralis* Guen.	Pyralidae	Lepidoptera
	Lamprosema diemenalis Guen.	Pyralidae	Lepidoptera
	L. vulgaris Guen.	Pyralidae	Lepidoptera
	Maruca vitrata (Geyer)	Pyralidae	Lepidoptera
	Nephopteryx leucophaella Zell.	Pyralidae	Lepidoptera
	Notarcha derogata Fabr.	Pyralidae	Lepidoptera
	Psara stultalis Walk.	Pyralidae	Lepidoptera
	Syngamia sp.	Pyralidae	Lepidoptera
Plume moth	*Exelastis atomosa* W.	Pterophoridae	Lepidoptera
	Sphenarches caffer Zell.	Pterophoridae	Lepidoptera
	Lampides boeticus L.	Lycaenidae	Lepidoptera
Pod borer	*Catochrysops cnejus* F.	Lycaenidae	Lepidoptera
	C. strabo (Fabr.)	Lycaenidae	Lepidoptera
	Boarmi trispinaria Walk.	Geometridae	Lepidoptera
	Hemithia sp.	Geometridae	Lepidoptera
Looper caterpillar	*Pingasa ruginaria* G.	Geometridae	Lepidoptera
Lobster caterpillar	*Stauropus alternus* Moore	Notodontidae	Lepidoptera
	Amsacta albistriga Walk.	Arctiidae	Lepidoptera
	A. lactinea (Cr.)	Arctiidae	Lepidoptera

	A. moorei Butler	Arctiidae	Lepidoptera
Green semilooper	*Azazia rubricans* B.	Noctuidae	Lepidoptera
	Chloridea obsolata Fabr.	Noctuidae	Lepidoptera
	Chrysodeixis eriosoma D.	Noctuidae	Lepidoptera
	Clethera floccifera Hampson	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
Pod borer	*Nanaguna breviuscula* Walker	Noctuidae	Lepidoptera
	Remigea archesis (Cram.)	Noctuidae	Lepidoptera
	Euproctis fraterna M.	Lymantriidae	Lepidoptera
	Lymantria ampla (Walk.)	Lymantriidae	Lepidoptera
Tussock caterpillar	*Olene mendosa* lib.	Lymantriidae	Lepidoptera
	Porthesia scintillans W.	Lymantriidae	Lepidoptera
	P. xanthorrhoea (Kollar)	Lymantriidae	Lepidoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Pod borer	*Melanagromyza obtusa* (Malloch.)	Agromyzidae	Diptera
Nodule fly	*Rivellia angulata*	Agromyzidae	Diptera
Leaf cutter bee	*Megachile anthracina* S.	Megachilidae	Hymenoptera
	M. disjuncts F.	Megachilidae	Hymenoptera
Seed wasp	*Bruchophagus mellipes* Gaham	Eurytomidae	Hymenoptera
Ant	*Solenopsis geminata* F.	Formicidae	Hymenoptera
	Ceratina binghami Ckll.	Apidae	Hymenoptera
Pod wasp	*Tanaostigmodes cajaninae* La Salle	Tanaostigmatidae	Hymenoptera
Stemborer	*Sphenoptera perotetti* G.	Buprestidae	Coleoptera
	Cantharis setacea	Cantharidae	Coleoptera
	Mylabris phalarata Pallas	Meloidae	Coleoptera
	Mylabris pustulata Th.	Meloidae	Coleoptera
	Epilachna dodecastigma (Wied.)	Coccinellidae	Coleoptera
	Bruchus theobromae L.	Bruchidae	Coleoptera
	Callasobruchus chinensis (I.)	Bruchidae	Coleoptera
	Dermarchus pubipennis J	Chrysomelidae	Coleoptera
	Leuoperomorpha vittata Duv.	Chrysomelidae	Coleoptera
	Luperus puncticollis J.	Chrysomelidae	Coleoptera
	Pagria signata (Mots.)	Chrysomelidae	Coleoptera
	Monolepta signata (Oliv.)	Galeuricidae	Coleoptera
	Pachnephorus sp.	Eumolpidae	Coleoptera
Seed weevil	*Apion benignum*	Curculionidae	Coleoptera
Seed weevil	*A. clavipes* Gerst.	Curculionidae	Coleoptera
Stem weevil	*Colobodes dolichotis* Mshll.	Curculionidae	Coleoptera
	Episomus lacerta F.	Curculionidae	Coleoptera
Bud weevil	*Indozocladius asperulus* (Fst.)	Curculionidae	Coleoptera
Leaf beetle	*Myllocerus discolor* var. *variegatus*	Curculionidae	Coleoptera
	M. maculosus Desbr.	Curculionidae	Coleoptera
	***Cicer arietinum* (BENGALGRAM)**		
Grasshopper	*Acrotylus humbertiana* S.	Acrididae	Orthoptera
	Aiolopus simulatrix simulatrix Wlk.	Acrididae	Orthoptera
Surface grasshopper	*Atractomorpha crenulata* F.	Acrididae	Orthoptera

	Catantops erubescens Wlk.	Acrididae	Orthoptera
	Chrotogonus brachypterus K.	Acrididae	Orthoptera
	Cyrtacanthacris tatarica (L.)	Acrididae	Orthoptera
	Eyprepocnemis alacris alacris S.	Acrididae	Orthoptera
	Pyrgomorpha sp.	Acrididae	Orthoptera
Cow bug	*Tricentrus bicolor* Dist.	Membracidae	Hemiptera
Aphid	*Aphis gossypii* Koch.	Aphididae	Hemiptera
White-tailed mealybug	*Ferrisia virgata* (Ckll.)	Pseudococcidae	Hemiptera
Termite	*Odontotermes* sp.	Termitidae	Hemiptera
Fig moth	*Cadra cautella* (Wlk.)	Pyralidae	Lepidoptera
Pod borer	*Etiella zinckenella* (Tr.)	Pyralidae	Lepidoptera
Pod borer	*Maruca vitrata* (Geyer)	Pyralidae	Lepidoptera
Leaf webber	*Omiodes indicata* (F.)	Pyralidae	Lepidoptera
Green semilooper	*Thysanoplusia orichalcea*	Noctuidae	Lepidoptera
Surface cutworm	*Agrotis biconica* Koll.	Noctuidae	Lepidoptera
Cutworm	*A. flammatra* S.	Noctuidae	Lepidoptera
Cutworm	*Agrotis ipsilon* (Hufn.)	Noctuidae	Lepidoptera
	A. segetum S.	Noctuidae	Lepidoptera
	A. spinifera H.	Noctuidae	Lepidoptera
	Azazia rubricans B.	Noctuidae	Lepidoptera
	Chrysodeixis chalcites Esp.	Noctuidae	Lepidoptera
	Diachrysia orichalcea F.	Noctuidae	Lepidoptera
Gram pod borer	*Helicoverpa armigera* (Hb.)	Noctuidae	Lepidoptera
Semilooper	*Plusia signata* F.	Noctuidae	Lepidoptera
Cutworm	*Mythimna loreyi* (Dup.)	Noctuidae	Lepidoptera
	M. separata (Wlk.)	Noctuidae	Lepidoptera
	Rhyacia herculea C.&D.	Noctuidae	Lepidoptera
	Spodoptera exigua (Hb.)	Noctuidae	Lepidoptera
	S. litura (F.)	Noctuidiae	Lepidoptera
	Lampides boeticus Linn.	Lycaenidae	Lepidoptera
Podfly	*Melanagromyza obtusa* (Mall.)	Agromyzidae	Diptera
Surface weevil	*Tanymecus indicus* Fst.	Curculionidae	Coleoptera
	T. tetricus Est.	Curculionidae	Coleoptera
	Luperodes sp.	Chrysomelidae	Coleoptera
Seed bruchid	*Callosobruchus chinensis* (L.)	Bruchidae	Coleoptera
	C. maculatus (f.)	Bruchidae	Coleoptera

Dolichos biflorus **(HORSEGRAM)**

Green plant bug	*Nezara viridula* Linn.	Pentatomidae	Hemiptera
Pod borer	*Etiella zinckenella* Treit.	Pyralidae	Lepidoptera
Leaf webber	*Omiodes indicata* (F.)	Pyralidae	Lepidoptera
Leaf webber	*Amsacta albistriga* Wlk.	Arctiidae	Lepidoptera
	A. lactinea (Cr.)	Arctiidae	Lepidoptera
	A. morrei Wlk.	Arctiidae	Lepidoptera
	Spilarctia obliqua (Wlk.)	Arctiidae	Lepidoptera
Green leaf caterpillar	*Anticarsia irrorata* B.	Noctuidae	Lepidoptera

Glycine max (SOYBEAN)

Grasshopper	*Atractomorpha crenulata* F.	Acrididae	Orthoptera
Field cricket	*Brachytrypes portentosus* (Licht.)	Acrididae	Orthoptera
	Loxoblemmus macrocephalus (Chopard)	Acrididae	Orthoptera
	Modicogryllus minimum (Chopard)	Acrididae	Orthoptera
	Teleogryllus mitratus (Burmeister)	Acrididae	Orthoptera
Mealy bug	*Nipaecoccus vastator* (Mask.)	Pseudococcidae	Hemiptera
Whitefly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	Hemiptera
Jassid	*Apheliona maculosa* Dist.	Delphacidae	Hemiptera
Pod bug	*Chauliops fallax* Scott.	Lygaeidae	Hemiptera
Green bug	*Nezara viridula* L.	Pentatomidae	Hemiptera
	Piezodorus rubrofasciatus Fab.	Pentatomidae	Hemiptera
Leaf thrips	*Ayyaria chaetophora* Ky.	Thripidae	Thysanoptera
Flower thrips	*Frankliniella schultezi* Trybom	Thripidae	Thysanoptera
	Megalurothrips usitatus (Bagnall)	Thripidae	Thysanoptera
	Ramaswamiahiella subnudula Ky.	Thripidae	Thysanoptera
	Haplothrips ceylonicus Schm.	Phaleothripidae	Thysanoptera
Leaf webber	*Anarsia ephippias* Meyr.	Gelechiidae	Lepidoptera
Groundnut leaf miner	*Aproaerema modicella* D.	Gelechiidae	Lepidoptera
Leaf roller	*Gracillaria soyella* D.	Gracillariidae	Lepidoptera
	Lamprosema dieminalis Guen.	Pyralidae	Lepidoptera
Leaf roller	*Omiodes indicata* (F.)	Pyralidae	Lepidoptera
Leaf caterpillar	*Spoladea (=Hymenia) recurvalis* (Fb.)	Pyralidae	Lepidoptera
	Spilarctia obliqua (Wlk.)	Arctiidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
Grey semilooper	*Rivula biocualis* Moore	Noctuidae	Lepidoptera
	Spodoptera litura (F.)	Noctuidae	Lepidoptera
Pea stem fly	*Melanagromyza phaseoli* Coq.	Agromyzidae	Diptera
Bean fly	*M. sojae* (Zehnt.)	Agromyzidae	Diptera
	Mylabris pustulata Th.	Meloidae	Coleoptera
	Nupserha bicolor F.	Cerambycidae	Coleoptera
Stem borer	*Oberea brevis* S.	Cerambycidae	Coleoptera

Lablab purpureus (=niger) (COUNTRY BEAN, INDIAN BEAN)

Wingless grasshopper	*Neorthacris simulans* B.	Acrididae	Orthoptera
Cow bug	*Anchon pilostini W.*	Membracidae	Hemiptera
Cotton white fly	*Bemisia tabaci* (Genn.)	Aleyrodidae	Hemiptera
Castor white fly	*Trialeurodes ricini* (Misra)	Aleyrodidae	Hemiptera
Plant lice	*Aphis craccivora* Koch.	Aphididae	Hemiptera
	Ceroplastodes cajani Mask.	Coccidae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
	Phenacoccus iceryoides Gr.	Pseudococcidae	Hemiptera
Bean bug	*Chauliops nigrescens* Dist.	Lygaeidae	Hemiptera
	Riptortus pedestris F.	Coreidae	Hemiptera

	Coptosoma cribraria F.	Plataspididae	Hemiptera
Flower thrips	*Haplothrips vernoniae* Pr.	Phlaeothripidae	Thysanoptera
Leaf thrips	*Ayyaria chaetophora* Ky.	Thripidae	Thysanoptera
Flower thrips	*Frankliniella schultzei* Trybom	Thripidae	Thysanoptera
	Megalurothrips usitatus (Bagnall)	Thripidae	Thysanoptera
Leaf miner	*Cosmopteryx phaeogastra* Meyr.	Cosmopterygidae	Lepidoptera
	Cyphosticha coerulea Meyr.	Gracillariidae	Lepidoptera
	Thosea aperiens Wlk.	Limacodiidae	Lepidoptera
	Laspeyresia torodelta Meyr.	Eucosmidae	Lepidoptera
Pod borer	*Etiella zinckenella* Treit.	Pyralidae	Lepidoptera
Leaf webber	*Omiodes indicata* F.	Pyralidae	Lepidoptera
	Exelastis atomosa Wism.	Pterophoridae	Lepidoptera
Hairy caterpillar	*Eupterote testacea* Walk.	Bombycidae	Lepidoptera
	Acherontia lachesis	Sphingidae	Lepidoptera
	A. styx W.	Sphingidae	Lepidoptera
Black hairy caterpillar	*Amsacta lactinea* (Cr.)	Arctiidae	Lepidoptera
	Pericallia ricini F.	Arctiidae	Lepidoptera
	Spilarctia obliqua (Wlk.)	Arctiidae	Lepidoptera
Hairy caterpillar	*Euproctis icilia* Stoll.	Lymantriidae	Lepidoptera
Tussock hairy caterpillar	*Olene mendosa* Hb.	Lymantriidae	Lepidoptera
Hairy caterpillar	*Porthesis scintillans* Wlk.	Lymantriidae	Lepidoptera
Green leaf caterpillar	*Anticarsia irrorata* F.	Noctuidae	Lepidoptera
Pod borer	*Adisura atkinsoni* M.	Noctuidae	Lepidoptera
	Azazia rubricans B.	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Stem fly	*Melanagromyza phaseoli* Coq.	Agromyzidae	Diptera
	Bruchus theobromae L.	Bruchidae	Coleoptera
Leaf hispid	*Platypria hystrix* Fb.	Hispidae	Coleoptera
Stem borer	*Sagra nigrita* Oliv.	Sagridae	Coleoptera
Stem weevil	*Alcidodes collaris* Pasc.	Curculionidae	Coleoptera
	A. pictus Boh.	Curculionidae	Coleoptera
	Colobodes dolichotis Mshll.	Curculionidae	Coleoptera
	Desmidophorus sp.	Curculionidae	Coleoptera
	Episomus lacerta F.	Curculionidae	Coleoptera

Phaseolus aconitifolius (MOTH BEAN)

Pod bug	*Chauliops fallax* Scott	Lygaeidae	Hemiptera
Leafroller	*Eucosma melanaula* Meyr.	Eucosmidae	Lepidoptera
	Amsacta moorei Butl.	Arctiidae	Lepidoptera
	Chrysodeixis eriosoma D.	Noctuidae	Lepidoptera
Pea stemfly	*Melanagromyza phaseoli* Coq.	Agromyzidae	Diptera

Pisum sativum (PEA)

	Leptocentrus obliquus W.	Membracidae	Hemiptera
	Tricentrus bicolor Dist.	Membracidae	Hemiptera
	Bemisia tabaci (Genn.)	Aleyrodidae	Hemiptera

Pea aphid	*Acyrthosiphon pisum* (Harris)	Aphididae	Hemiptera
	Aphis craccivora Koch.	Aphididae	Hemiptera
	Creontiades stramineus (Walk.)	Miridae	Hemiptera
	Caliothrips indicus (Bagn.)	Thripidae	Thysanoptera
	Etiella zinckenella Treit.	Pyralidae	Lepidoptera
	Leucinodes orbonalis Guen.	Pyralidae	Lipidoptera
	Catechrysops cnejus Fb.	Lycaenidae	Lepidoptera
	Lampides boeticus L.	Lycaenidae	Lepidoptera
	Spilarctia obliqua (Wlk.)	Arctiidae	Lepidoptera
Cut worm	*Agrotis flammatra* (D. & J.)	Noctuidae	Lepidoptera
	A. ipsilon (Huf.)	Noctuidae	Lepidoptera
	Chrysodeixis eriosoma (D.)	Noctuidae	Lepidoptera
	Euxoa spinifera Hb.	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
	Mythimna separata (Wlk.)	Noctuidae	Lepidoptera
	Spodoptera exigua (Hb.)	Noctuidae	Lepidoptera
	S. litura (F.)	Noctuidae	Lepidoptera
	Thysanoplusia orichalcea (F.)	Noctuidae	Lepidoptera
Pea leaf miner	*Chromatomyia horticola (Gour)*	Agromyzidae	Diptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Pea stem fly	*Melanagromyza phaseoli* Coq.	Agromyzidae	Diptera
Sitonid weevil	*Sitona crinitus* (Herbst.)	Curculionidae	Coleoptera
	Tanymecus indicus Fst.	Curculionidae	Coleoptera

Vigna mungo (BLACK GRAM)

	Tricentrus bicolor Dist.	Membracidae	Hemiptera
	Aphis craccivora Koch.	Aphididae	Hemiptera
Mealy bug	*Dysmicoccus breviceps* (Ckll.)	Pseudococcidae	Hemiptera
	Chauliops fallax Scott	Lygaeidae	Hemiptera
	Riptortus pedestris F.	Coreidae	Hemiptera
Leaf roller	*Eucosma melanaula* Meyr.	Eucosmidae	Lepidoptera
Pod borer	*Hyalospila leuconeurella* Rag.	Pyralidae	Lepidoptera
	Maruca testulalis Geyer	Pyralidae	Lepidoptera
	Catochrysops cnejus F.	Lycaenidae	Lepidoptera
	Lampides boeticus L.	Lycaenidae	Lepidoptera
	Herse convolvuli L.	Sphingidae	Lepidoptera
Hairy caterpillar	*Amsacta lactinea* (Cr.)	Arctiidae	Lepidoptera
	A. moorei Butl	Arctiidae	Lepidoptera
	Spilarctia obliqua (Wlk.)	Arctiidae	Lepidoptera
Hairy caterpillar	*Porthesia scientillans* Wlk.	Lymantriidae	Lepidoptera
	Anomis flava F.	Noctuidae	Lepidoptera
	Anticarsia irrorata B.	Noctuidae	Lepidoptera
	Eublemma dimidialis F.	Noctuidae	Lepidoptera
	E. hemirrhoda Wlk.	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
	Melanagromyza phaseoli Coq.	Agromyzidae	Diptera

	Alcidodes collaris P.	Curculionidae	Coleoptera
	A. fabricii F.	Curculionidae	Coleoptera
	Apion ampulum Fst.	Apionidae	Coleoptera

Vigna radiata (GREEN GRAM)

Cow bug	*Tricentrus bicolor* Dist.	Membracidae	Hemiptera
	Chauliops fallax Scott	Lygaeidae	Hemiptera
Mealy bug	*Dysmicoccus breviceps* (Ckll.)	Pseudococcidae	Hemiptera
Root mealy bug	*Geococus coffeae* Green	Pseudococcidae	Hemiptera
	Aphis craccivora Koch.	Aphididae	Hemiptera
Whitefly	*Zaphanera publicus* (Singh)	Aleyrodidae	Hemiptera
	Riptortus pedestris F.	Coreidae	Hemiptera
Thrips	*Meglurothrips distalis* (Karny)	Thripidae	Thysanoptera
	Thrips palmi Karny	Thripidae	Thysanoptera
Shoot borer	*Anarsia ephippias* M.	Gelechiidae	Lepidoptera
Leafroller	*Eucosma melanaula* Meyr.	Eucosmidae	Lepidoptera
	Omiodes indicata (F.)	Pyralidae	Lepidoptera
Pod borer	*Maruca vitrata* (Geyer)	Pyralidae	Lepidoptera
	Catochrysops cnejus F.	Lycaenidae	Lepidoptera
	Lampides boeticus L.	Lycaenidae	Lepidoptera
	Herse convolvuli L.	Sphingidae	Lepidoptera
Black hairy caterpillar	*Amsacta lactinea* (Cr.)	Arctiidae	Lepidoptera
	Spilarctia obliqua (Wlk.)	Arctiidae	Lepidoptera
Hairy caterpillar	*Porthesia scintillans* Wlk.	Lymantriidae	Lepidoptera
Green leaf caterpillar	*Anticarsia irrorata* B.	Noctuidae	Lepidoptera
Green semilooper	*Azazia rubricans* B.	Noctuidae	Lepidoptera
	Eublemma hemirrhoda Wlk.	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Green leaf caterpillar	*Ceratina binghami* Ckll.	Apidae	Hymenoptera
	Mylabris pustulata Th.	Meloidae	Coleoptera
Seed borer	*Callosobruchus analis* F.	Bruchidae	Coleoptera
	Alcidodes collaris P.	Curculionidae	Coleoptera
	A. fabricii F.	Curculionidae	Coleoptera
	Pachytychius mungonis Mshll.	Curculionidae	Coleoptera
	Apion ampulum Fst.	Apionidae	Coleoptera

Vigna unguiculata (COWPEA)

Surface grasshopper	*Chrotogonus trachypterus* Bl.	Pyrgomorphidae	Orthoptera
'AK' grasshopper	*Poekilocerus pictus* F.	Acrididae	Orthoptera
Grasshopper	*Oxya nitidula* Willemse	Acrididae	Orthoptera
Cow bug	*Anchon pilosum* W.	Membracidae	Hemiptera
Cotton white fly	*Bemisia tabaci* (Genn.)	Aleyrodidae	Hemiptera
	Aphis craccivora Koch.	Aphididae	Hemiptera
Mealy bug	*Dysmicoccus breviceps* (Ckll.)	Pseudococcidae	Hemiptera
Green jassid	*Empoasca kerri* Pruthi	Cicadellidae	Hemiptera

Green bug	*Creontiades pallidifer* Wlk.	Miridae	Hemiptera
Pod bug	*Chauliops fallax* Scott.	Lygaeidae	Hemiptera
	Anoplocnemis phasiana F.	Coreidae	Hemiptera
	Riptortus linearis F.	Coreidae	Hemiptera
	R. pedestris F.	Coreidae	Hemiptera
Red cotton bug	*Dysdercus cingulatus* F.	Pyrrhocoridae	Hemiptera
Painted bug	*Bagrada cruciferarum* (Burm.)	Pentatomidae	Hemiptera
Green bug	*Nezara viridula* L.	Pentatomidae	Hemiptera
Pod caterpillar	*Anatrachyntis simplex* Wlsm.	Cosmopterygidae	Lepidoptera
Leaf miner	*Acrocercops phaeospora* Meyr.	Gracillariidae	Lepidoptera
Slug caterpillar	*Thosea aperiens* Wlk.	Limacodiidae	Lepidoptera
Pod borer	*Etiella zinckenella* Treit.	Pyralidae	Lepidoptera
Pod borer	*Maruca vitrata* (Geyer)	Pyralidae	Lepidoptera
	Catochrysops cnejus L.	Lycaenidae	Lepidoptera
	Lampides boeticus L.	Lycaenidae	Lepidoptera
	Amata passalis Fb.	Amatidae	Lepidoptera
	Amsacta albistriga Wlk.	Arctiidae	Lepidoptera
	A. lactinea (Cr.)	Arctiidae	Lepidoptera
	A. moorei Butl.	Arctiidae	Lepidoptera
Bihar hairy caterpillar	*Spilarctia obliqua* (Wlk.)	Arctiidae	Lepidoptera
	Anticarsia irrorata B.	Noctuidae	Lepidoptera
	Azazia rubricans B.	Noctuidae	Lepidoptera
	Eublemma hemirrhoda W.	Noctuidae	Lepidoptera
	Mocis frugalis F.	Noctuidae	Lepidoptera
	Proxenus hugeli Feld.	Noctuidae	Lepidoptera
	Thysanoplusia orichalcea (F.)	Noctuidae	Lepidoptera
	Euproctis fraterna M.	Lymantriidae	Lepidoptera
	Porthesia scintillans W.	Lymantriidae	Lepidoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Pea stem fly	*Melanagromyza phaseoli* Coq.	Agromyzidae	Diptera
Pea stem fly	*Ophiomyia centrosematis*	Agromyzidae	Diptera
White grub	*Anomala bengalensis* Blanch	Rutelidae	Coleoptera
Flower beetle	*Chiloloba acuta* Wiedmann	Rutelidae	Coleoptera
	Holotrichia consanguinea Bl.	Melolonthidae	Coleoptera
	H. insularis Brenske	Melolonthidae	Coleoptera
Flower beetle	*Mylabris pustulata* (Thunb.)	Meloidae	Coleoptera
Flower beetle	*Cantharis setacea*	Cantharidae	Coleoptera
Stem borer	*Oberea brevis* S.	Cerambycidae	Coleoptera
Pulse beetle	*Callosobruchus chinensis* (L.)	Bruchidae	Coleoptera
	Zabrotes fasciatus (Boh.)	Bruchidae	Coleoptera
	Lema sp.	Galeruicidae	Coleoptera
	Madurasia obscurella Jac.	Galeruicidae	Coleoptera
Red pumpkin beetle	*Raphidopalpa foveicollis* Lucas	Galeruicidae	Coleoptera
	Rhizopertha dominica (Fb.)	Bostrychidae	Coleoptera
	Crytozemia dispar Marshall	Curculionidae	Coleoptera
	Myllocerus undecimpustulatus Desbr.	Curculionidae	Coleoptera

VEGETABLES

Abelmoschus esculentus (LADY'S FINGER)

Rice smaller grasshopper	*Oxya nitidula* Willemse	Acrididae	Orthoptera
'AK' grasshopper	*Poekilocerus pictus* Fb.	Acrididae	Orthoptera
Cow bug	*Leptocentrus obliquus* W.	Membracidae	Hemiptera
	Tricentrus bicolor Dist.	Membracidae	Hemiptera
	Empoasca devastans Distant	Cicadellidae	Hemiptera
Cotton white fly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	Hemiptera
	Aphis gossypii G.	Aphididae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
	Nipaecoccus vastator (Mask.)	Pseudococcidae	Hemiptera
	Ceroplastes floridensis Comst.	Coccidae	Hemiptera
	Parasaissetia nigra (Neitner)	Coccidae	Hemiptera
	Saissetia hemisphaerica (Targ.)	Coccidae	Hemiptera
	S. privigna DeLotto	Coccidae	Hemiptera
Red cotton bug	*Dysdercus cingulatus* F.	Pyrrhocoridae	Hemiptera
Flower thrips	*Franklinielia schultzei* Trybom	Thripidae	Thysanoptera
	Thrips tabaci Lind.	Thripidae	Thysanoptera
	Haplothrips gowdeyi (Frank.)	Phlaeothripidae	Thysanoptera
Cotton pink bollworm	*Pectinophora gossypiella* Saund	Gelechiidae	Lepidoptera
Leafroller	*Syllepte derogata* F.	Pyralidae	Lepidoptera
Semilooper	*Acontia graellsi* F.	Noctuidae	Lepidoptera
	Anomis flava F.	Noctuidae	Lepidoptera
Greasy cutworm	*Agrotis ipsilon* (Hufn.)	Noctuidae	Lepidoptera
Spiny bollworm	*Earias insulana* Boisd.	Noctuidae	Lepidoptera
Spotted bollworm	*E. vittella* (F.)	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
	Tarache nitidula F.	Noctuidae	Lepidoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Stem fly	*Melanagromyza obtusa* (Mall.)	Agromyzidae	Diptera
Leaf miner	*Trachys herilla* Obenb.	Buprestidae	Coleoptera
	Paratrachys sp.	Buprestidae	Coleoptera
Scarabaid beetle	*Xylotrupes gideon* (L.)	Scarabeidae	Coleoptera
Flower beetle	*Mylabris pustulata* (Thumb)	Meloidae	Coleoptera
Flea beetle	*Podagrica bowringi* B.	Alticidae	Coleoptera
Shoot weevil	*Alcidodes affaber* F.	Curculionidae	Coleoptera
Leaf weevil	*Myllocerus discolor* var. *variegatus* Boh.	Curculionidae	Coleoptera
	M. maculosus Desbr.	Curculionidae	Coleoptera
	M. viridanus F.	Curculionidae	Coleoptera
	Ptochus ovulum Fst.	Curculionidae	Coleoptera
Flower beetle	*Oxycetonia versicolor* Fb.	Cetoniidae	Coleoptera

Amaranthus gangeticus (AMARANTHUS)

Grasshopper	*Chrotogonus* sp.	Pyrgomorphidae	Coleoptera
	Aphis craccivora Koch.	Aphididae	Hemiptera

	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
	Coccus hesperidum (Linn.)	Coccidae	Hemiptera
	Pulvinaria durantae T.	Coccidae	Hemiptera
Inflorescence thrips	*Euryaplothrips crassus* R. & M.	Thripidae	Thysanoptera
	Haplothrips ceylonicus Sch.	Phlaeothripidae	Thysanoptera
Leaf caterpillar	*Conogethes punctiferalis* (Guen.)	Phlaeothripidae	Lepidoptera
	Spoladea (= Hymenia) recurvalis (Fb.)	Pyralidae	Lepidoptera
Leaf webber	*Pachyzancla stultalis* (Wlk.)	Pyralidae	Lepidoptera
	Junonia orithya Linn.	Nymphalidae	Lepidoptera
	Othreis fullonica Linn.	Noctuidae	Lepidoptera
	O. materna Linn.	Noctuidae	Lepidoptera
Green semilooper	*Chrysodeixis eriosoma* (D.)	Noctuidae	Lepidoptera
	Spodoptera exigua (Hb.)	Noctuidae	Lepidoptera
Leaf eating caterpillar	*S. litura* Fb.	Noctuidae	Lepidoptera
Leaf folder	*Archips* sp.	Tortricidae	Lepidoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Tortoise beetle	*Cassida exilis* B.	Cassididae	Coleoptera
Amaranthus weevil	*Hypolixus truncatulus*	Curculionidae	Coleoptera
Stem weevil	*Paralixus brachyrrhinus* Boh.	Curculionidae	Coleoptera
	Ptochus ovulum Fst.	Curculionidae	Coleoptera

Amorphophallus campanulatus (ELEPHANT'S FOOT YAM)

Scale insect	*Aspidiella hartii* Ckll.	Diaspididae	Hemiptera
Horned caterpillar	*Hippotion celerio* (Linn.)	Sphingidae	Lepidoptera
Horned caterpillar	*Rhyncholaba actens* (Cramer)	Sphingidae	Lepidoptera
Horned caterpillar	*Theretra gnoma* (Fb.)	Sphingidae	Lepidoptera
Leaf beetle	*Gelerucida bicolor* Hope	Galerucidae	Coleoptera

Artocarpus incisa (BREADFRUIT)

Plant lice	*Greenidia artocarpi* (Westw.)	Aphididae	Hemiptera
	Toxoptera aurantii (Bd. F.)	Aphididae	Hemiptera
Scale insect	*Icerya aegyptiaca* D.	Margarodidae	Hemiptera
	Araecerus fasciculatus (De G.)	Anthribidae	Coleoptera

Benincasa cerifera (ASH PUMPKIN)

Scale insect	*Pinnaspis temporaria* Ferris	Diaspididae	Hemiptera
Flower thrips	*Frankliniella schultzei* Trybom	Thripidae	Thysanoptera
	Thrips tabaci Lind	Thripidae	Thysanoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Red beetle	*Raphidopalpa foveicollis* (Lucas)	Galerucidae	Coleoptera

Beta vulgaris (BEET ROOT)

Cabbage borer	*Hellula undalis* Fb.	Pyralidae	Lepidoptera
Leaf caterpillar	*Spoladea recurvalis* (Fb.)	Pyralidae	Lepidoptera
	Agrotis ipsilon (Hufn.)	Noctuidae	Lepidoptera

	Spodoptera litura (F.)	Noctuidae	Lepidoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Leaf weevil	*Ptochus ovulum* Fst.	Curculionidae	Coleoptera

Brassica oleracea var. *botrytis* (CAULIFLOWER)

Bombay locust	*Patanga succincta* (Linn.)	Acrididae	Orthoptera
Cow bug	*Tricentrus bicolor* Dist.	Membracidae	Hemiptera
	Lipaphis erysimi Kalt.	Aphididae	Hemiptera
	Myzus persicae S.	Aphididae	Hemiptera
Mealy bug	*Planococcus lilacinus* (Ckll.)	Pseudococcidae	Hemiptera
	Bagrada cruciferarum F.	Pentatomidae	Hemiptera
	B. hilaris (Burm.)	Pentatomidae	Hemiptera
	Caliothrips indicus (Bagnall)	Thripidae	Thysanoptera
	Thrips tabaci Lind.	Thripidae	Thysanoptera
Diamond back moth	*Plutella xylostella* (L.)	Plutellidae	Lepidoptera
Leaf webber	*Crocidolomia pavonana* F.	Pyralidae	Lepidoptera
Cabbage borer	*Hellula undalis* Fb.	Pyralidae	Lepidoptera
	Spilarctia obliqua (Wlk.)	Arctiidae	Lepidoptera
Greasy cutworm	*Agrotis ipsilon* (Hufn.)	Noctuidae	Lepidoptera
Cutworm	*A. segetum* Schiff.	Noctuidae	Lepidoptera
Leaf caterpillar	*Spodoptera litura* (F.)	Noctuidae	Lepidoptera
Cutworm	*Xestia c-nigrum* (L.)	Noctuidae	Lepidoptera
Cabbage semilooper	*Trichoplusia ni* (Hb.)	Noctuidae	Lepidoptera
Pea leafminer	*Chromatomyia horticola* (Gour)	Agromyzidae	Diptera
Mustard sawfly	*Athalia proxima* (Klug)	Tenthredinidae	Hymenoptera
	Dorylus orientalis W.	Formicidae	Hymenoptera

Brassica oleracea var. *capitata* (CABBAGE)

Surface grasshopper	*Chrotogonus trachypterus* Ol.	Pyrgomorphidae	Orthoptera
Short-horned grasshopper	*Atractomorpha crenulata* Fb.	Acrididae	Orthoptera
Bombay locust	*Patanga succincta* (Linn.)	Acrididae	Orthoptera
Groundnut earwig	*Euborellia annulipes* Lucas	Forficulidae	Dermaptera
Cow bug	*Tricentrus bicolor* Dist.	Membracidae	Hemiptera
Aphids	*Brevicoryne brassicae* Linn.	Aphididae	Hemiptera
	Lipaphis erysimi Kalt.	Aphididae	Hemiptera
	Myzus persicae S.	Aphididae	Hemiptera
	Bagrada cruciferarum F.	Pentatomidae	Hemiptera
Thrips	*Caliothrips indicus* (Bagnall)	Thripidae	Thysanoptera
	Frankliniella schultzei P.	Thripidae	Thysanoptera
	Thrips tabaci Lind.	Thripidae	Thysanoptera
Diamond back moth	*Plutella xylostella* (L.)	Plutellidae	Lepidoptera
Leaf webber	*Crocidolomia pavonana* F.	Pyralidae	Lepidoptera
Cabbage borer	*Hellula undalis* Fb.	Pyralidae	Lepidoptera
	Spilarctia obliqua (Wlk.)	Arctiidae	Lepidoptera
Cabbage butterfly	*Pieris brassicae* (Linn.)	Pieridae	Lepidoptera
Greasy cutworm	*Agrotis ipsilon* (Hufn.)	Noctuidae	Lepidoptera

	A. segetum (Schiff.)	Noctuidae	Lepidoptera
	Chrysodeixis chalcites Esp.	Noctuidae	Lepidoptera
	C. erisoma (D.)	Noctuidae	Lepidoptera
	Plusia signata Fb.	Noctuidae	Lepidoptera
Leaf caterpillar	*Spodoptera litura* (F.)	Noctuidae	Lepidoptera
Green semilooper	*Thysanoplusia orichalcea* Fb.	Noctuidae	Lepidoptera
Cabbage semilooper	*Trichoplusia ni* (Hb.)	Noctuidae	Lepidoptera
Cutworm	*Xestia c-nigrum* (L.)	Noctuidae	Lepidoptera
Pea leaf miner	*Chromatomyia horticola* (Gour)	Agromyzidae	Diptera
Mustard sawfly	*Athalia proxima* (Klug)	Tenthredinidae	Hymenoptera
	Dorylus orientalis W.	Formicidae	Hymenoptera
Spinach beetle	*Haltica caerulescens* Baly.	Alticidae	Coleoptera
Cabbage flea beetle	*Phyllotreta cruciferae* (George)	Alticidae	Coleoptera

Brassica oleracea var. _gongylodes_ (KNOLKHOL)

	Caliothrips indicus (Bagnall)	Thripidae	Thysanoptera
Diamond back moth	*Plutella xylostella* (L.)	Plutellidae	Lepidoptera
Cabbage borer	*Hellula undalis* Fb.	Pyralidae	Lepidoptera
Pea leaf miner	*Chromatomyia horticola* (Gour)	Agromyzidae	Diptera
Flea beetle	*Chaetocnema basalis* Bally.	Alticidae	Coleoptera

Brassica olerace var. _rapa_ (TURNIP)

Pea leafminer	*Chromatomyia horticola* (Gour)	Agromyzidae	Diptera
Mustard sawfly	*Athalia proxima* (Klug.)	Tenthredinidae	Hymenopter
Flea beetle	*Chaetocnema basalis* Bally	Alticidae	Coleoptera

Citrullus vulgaris (WATER and SNAP MELONS)

Cotton white fly	*Bemisia tabaci* (Genn.)	Aleyrodidae	Hemiptera
Leaf caterpillar	*Glyphodes caesalis* S.	Pyralidae	Lepidoptera
Fruitfly	*Bactrocera ciliatus* Loew.	Tephritidae	Diptera
	B. cucurbitae Coq.	Tephritidae	Diptera
	B. diversus Coq.	Tephritidae	Diptera
Flower beetles	*Mylabris phalerata*	Meloidae	Coleoptera
	M. pustulata (*Th.*)	Meloidae	Coleoptera
Grey beetle	*Aulacophora cincta* Fabr.	Galerucidae	Coleoptera
Red beetle	*Aulacophora foveicollis* (Lucas)	Galerucidae	Coleoptera
Blue beetle	*A. lewsii* Baly.	Galerucidae	Coleoptera

Coccinia indica (COCCINIA)

Cucurbit aphid	*Aphis malvae* Koch.	Aphididae	Hemiptera
Leafhopper	*Empoasca* sp.	Cicadellidae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
	Saissetia hemisphaerica (Targ.)	Coccidae	Hemiptera
	Aspongopus obscurus F.	Pentatomidae	Hemiptera
Vine borer	*Melittia eurytion* Westw.	Sessiidae	Lepidoptera
Leaf folder	*Glyphodes indica* (S.)	Pyralidae	Leipdoptera

Woolly bear	*Pericallia ricini* Fb.	Arctiidae	Lepidoptera
	Spodoptera litura (F.)	Noctuidae	Lepidoptera
Stem gall midge	*Lasioptera cephalandrae Mani*	Cecidomyiidae	Diptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Fruitfly	*Bactrocera ciliatus* Loew.	Tephritidae	Diptera
	B. cucurbitae Coq.	Tephritidae	Diptera
Spotted leaf beetle	*Epilachna implicata* Muls.	Coccinellidae	Coleoptera
Vine borer	*Apomecyna histrio* Fb.	Cerambycidae	Coleoptera
	A. pertigera Thoms.	Cerambycidae	Coleoptera
	A. perotetti	Cerambycidae	Coleoptera
	A. saltator	Cerambycidae	Coleoptera
Weevil	*Acythopius citrulli* Mshll.	Curculionidae	Coleoptera

Coleus parviflora **(CHINESE POTATO, KOORKAN)**

Top shoot folder	*Phostria piasusalis* W.	Pyralidae	Lepidoptera
Leaf folder	*Aripana (= Pycnarmon) cribrata* (F.)	Pyralidae	Lepidoptera
Amaranthus caterpillar	*Spoladea recurvalis* (Fb.)	Pyralidae	Lepidoptera
Stem borer	*Nupserha vexator* P.	Cerambycidae	Coleoptera

Colocasia esculenta **(*C. antiquorum*) (TARO, YAM)**

Grasshopper	*Gesonula punctifrons* Stal.	Acrididae	Orthoptera
Banana aphid	*Pentalonia nigronervosa* Coq.	Aphididae	Hemiptera
Aphid	*P. galadii* D.	Aphididae	Hemiptera
Banana lacewing bug	*Stephanitis typica* Dist.	Tingidae	Hemiptera
Leaf thrips	*Caliothrips indicus* (Bagnall)	Thripidae	Thysanoptera
	Helionothrips kadaliphilus (R. & M.)	Thripidae	Thysanoptera
	Heliothrips haemorrhoidalis B.	Thripidae	Thysanoptera

Cucumis melo **(MUSK MELON)**

Cotton white fly	*Bemisia tabaci* (Genn.)	Aleyrodidae	Hemiptera
Leaf caterpillar	*Glyphodes caesalis* S.	Pyralidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
Fruitfly	*Bactrocera ciliatus* Loew.	Tephritidae	Diptera
	B. cucurbitae Coq.	Tephritidae	Diptera
	B. diversus Coq.	Tephritidae	Diptera
Flower beetles	*Mylabris phalerata*	Meloidae	Coleoptera
	M. pustulata (Th.)	Meloidae	Coleoptera
Grey beetle	*Aulacophora cincta* Fabr.	Galerucidae	Coleoptera
Blue beetle	*A. lewsii* Baly.	Galerucidae	Coleoptera
Red beetle	*Aulacophora foveicollis* (Lucas)	Galerucidae	Coleoptera
	Acythopius citrulli Mshll.	Curculionidae	Coleoptera

Cyamopsis tetragonoloba **(CLUSTER BEANS)**

Plant lice	*Aphis craccivora* Koch.	Aphididae	Hemiptera
Cotton white fly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	Hemiptera
	Coptosoma cribraria F.	Plataspididae	Hemiptera
	C. nazirae At.	Plataspididae	Hemiptera

	Cyclopelta siccifolia Westw.	Pentatomidae	Hemiptera
Flower thrips	*Megalurothrips distalis* (Bagnall)	Thripidae	Thysanoptera
Blossom midge	*Asphondylia* sp.	Cecidomyiidae	Diptera
Serpentine leaf miner	*Liriomyza trifolli* (Burgess)	Agromyzidae	Diptera
	Alcidodes bubo F.	Curculionidae	Coleoptera
	Blosyrus inaqualis B.	Curculionidae	Coleoptera
Blossom midge	*Crytozenia coquata* Mshll.	Curculionidae	Coleoptera
	C. dispar Mshll.	Curculionidae	Coleoptera
	Myllocerus maculosus Desbr.	Curculionidae	Coleoptera

Daucus carota (CARROT)

Pea leafminer	*Chromatomyia horticola* (Gour)	Agromyzidae	Diptera
	Chlorophorus sp.	Cerambycidae	Coleoptera
Flea beetle	*Chaetocnema basalis* Bally	Alticidae	Coleoptera
	Anthrenus ocenicus Favrel	Dermestidae	Coleoptera
Flea beetle	*A. coloratus* Rottenburg	Dermestidae	Coleoptera
	A. jordanicus Pic.	Dermestidae	Coleoptera

Ipomoea batatas (SWEET POTATO)

Root mealy bug	*Geococcus coffeae* Green	Pseudococcidae	Hemiptera
Leaf folder	*Brachmea effera* Meyr.	Gelechiidae	Lepidoptera
Stemborer	*Omphisa anastomosalis* G.	Pyralidae	Lepidoptera
	Pericallia ricini F.	Arctiidae	Lepidoptera
	Spilarctia obliqua (Wlk.)	Arctiidae	Lepidoptera
Hairy caterpillar	*Euchromia polymena* L.	Amatidae	Lepidoptera
	Junonia orithya L.	Nymphalidae	Lepidoptera
Horned caterpillar	*Herse convolvuli* L.	Sphingidae	Lepidoptera
Leaf caterpillar	*Catephia inquieta* W.	Noctuidae	Lepidoptera
	C. leucomelas L.	Noctuidae	Lepidoptera
	Spodoptera litura (F.)	Noctuidae	Lepidoptera
White grub	*Holotrichia consanguinea* Bl.	Melolonthidae	Coleoptera
Leaf miner	*Trachys ipomoeae* Th.	Buprestidae	Coleoptera
	Onchocephala tuberculata OI.	Hispidae	Coleoptera
Tortoise beetle	*Aspidomorpha furcata* Thunb.	Cassididae	Coleoptera
	A. miliaris F.	Cassididae	Coleoptera
	Chirida bipunctata F.	Cassididae	Coleoptera
	Metriona circumdata H.	Cassididae	Coleoptera
Green leaf beetle	*Colasposoma metallicum* C.	Eumolpidae	Coleoptera
Capsule weevil	*Alcidodes fabricii* F.	Curculionidae	Coleoptera
Sweet potato weevil	*Cylas formicarius* Fb.	Apionidae	Coleoptera

Lagenaria vulgaris (BOTTLE GOURD)

Green bug	*Nesidiocoris caesar* (Ballard)	Miridae	Hemiptera
Chillies thrips	*Scirtothrips dorsalis* Hood	Thripidae	Thysanoptera
Plume moth	*Sphenarches caffer* Z.	Pterophoridae	Lepidoptera
Red beetle	*Aulacophora foveicollis* (Lucas)	Galerucidae	Coleoptera

Luffa acutangula (RIBBED GOURD)

Plant bug	*Riptortus pedestris* F.	Coreidae	Hemiptera
Leaf thrips	*Taeniothrips claratris* Shumsher	Thripidae	Thysanoptera
Leaf caterpillar	*Spoladea recurvalis* (Fb.)	Pyralidae	Lepidoptera
Fruit fly	*Bactrocera cucurbitae* Coq.	Tephritidae	Diptera
Blue beetle	*Aulacophora lewisii* Jacoby	Galerucidae	Coleoptera
Red beetle	*A. foveicollis* (Lucas)	Galerucidae	Coleoptera

Luffa aegyptica (RIDGE GOURD)

Rice smaller grasshopper	*Oxya nitidula* Willemse	Acrididae	Orthoptera
Onion thrips	*Thrips tabaci* Lind	Thripidae	Thysanoptera
Serpentine leaf miner	*Liriomyza trifolli* (Burgess)	Agromyzidae	Diptera

Luffa cylindrica (SPONGE GOURD)

Blue beetle	*Aulacophora lewisii* Jacoby	Galerucidae	Coleoptera
Red beetle	*Aulacophora foveicollis* (Lucas)	Galerucidae	Coleoptera

Lycopersicum esculentum (TOMATO)

Field cricket	*Brachytrypes portentosus* (Licht.)	Acrididae	Orthoptera
	Loxoblemmus macrocephalus (Chopard)	Acrididae	Orthoptera
	Modicorgryllus minimus (Chopard)	Acrididae	Orthoptera
	Teleogryllus mitratus (Burmeister)	Acrididae	Orthoptera
Cowbug	*Tricentrus bicolor* Dist.	Membracidae	Hemiptera
Cotton white fly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	Hemiptera
White tailed mealy bug	*Ferrisia virgata* (Ckll.)	Pseudococcidae	Hemiptera
	Cryptopeltis crassicornis Dist.	Miridae	Hemiptera
Flower thrips	*Haplothrips ganglbaurei* Schm.	Phlaeothripidae	Thysanoptera
Leaf thrips	*Caliothrips indicus* (Bagnl)	Thripidae	Thysanoptera
	Frankliniella schultzei Trybom	Thripidae	Thysanoptera
	Megalurothrips usitatus (Bagnall)	Thripidae	Thysanoptera
	Scirtothrips dorsalis Hood	Thripidae	Thysanoptera
Fruit sucking moth	*Phthorimaea operculella* Z.	Gelechiidae	Lepidoptera
	Euzophera perticella Rag.	Pyralidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
	Othreis fullonica L.	Noctuidae	Lepidoptera
Fruit sucking moth	*O. homaena*	Noctuidae	Lepidoptera
Fruit sucking moth	*O. maternal* L.	Noctuidae	Lepidoptera
	Spodoptera litura (F.)	Noctuidae	Lepidoptera
Cabbage green semilooper	*Trichoplusia ni* (Hb.)	Noctuidae	Leipdoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Spotted beetle	*Epilachna vigintioctopunctata* F.	Coccinellidae	Coleoptera

Manihot utilissima (TAPIOCA, CASSAVA)

Termite	*Odontotermes obesus* R.	Termitidae	Isoptera
Whitefly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	Hemiptera
Cassava scale	*Aonidomytilus albus* Ckll.	Diaspididae	Hemiptera
Black scale	*Parasaissetia nigra* (Niet.)	Coccidae	Hemiptera
Thrips	*Retithrips syriacus* (Mayet)	Thripidae	Thysanoptera
Leaf beetle	*Apogonia rauca* Fletcher	Melolonthidae	Coleoptera

Momordica charantia (BITTER GOURD)

Cotton whitefly	*Bemisia tabaci* (Genn.)	Aleyrodidae	Hemiptera
Aphid	*Aphis gossypii* Gl.	Aphididae	Hemiptera
Plant lice	*Aphis malvae* Koch.	Aphididae	Hemiptera
Flower thrips	*Frankliniella schultzei* Trybom	Thripidae	Thysanoptera
Onion thrips	*Thrips tabaci* Lind.	Thripidae	Thysanoptera
Leaf roller	*Glyphodes indica* (S.)	Pyralidae	Lepidoptera
	Leucinodes orbonalis Guen.	Pyralidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
Fruitfly	*Bactrocera ciliatus* Loew.	Tephritidae	Diptera
	B. cucurbitae Coq.	Tephritidae	Diptera
Steam gall midge	*Lasioptera falcata* (Felt)	Cecidomyiidae	Diptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Leaf spotted beetle	*Epilachna implicata* Muls.	Coccinellidae	Coleoptera
	E. septima Dieke	Coccinellidae	Coleoptera

Momordica dioica (KAKORA)

Hadda beetle	*Epilachna demurili* Fb.	Coccinellidae	Coleoptera

Moringa oleifera (MORINGA or DRUMSTICK)

Plant licp	*Aphis craccivora* Koch.	Aphididae	Hemiptera
	Bemisia moringae (David & Sub.)	Aleyrodidae	Hemiptera
Castor whitefly	*Trialeurodes ricini* (Misra)	Aleyrodidae	Hemiptera
Scale insect	*Ceroplastodes cajani* M.	Coccidae	Hemiptera
	Diaspidiotus sp.	Diaspididae	Hemiptera
	Cyclopelta siccifolia Westw.	Pentatomidae	Hemiptera
Flower thrips	*Ramaswamiahiella subnudula* Karny	Thripidae	Thysanoptera
	Scirtothrips dorsalis Hood	Thripidae	Thysanoptera
Bark caterpillar	*Indarbela tetraonis* Moore	Metarbelidae	Lepidoptera
Leaf caterpillar	*Noorda blitealis* W.	Pyralidae	Lepidoptera
Budworm	*N. moringae* Tams.	Pyralidae	Lepidoptera
	Protrigonia zizanealis S.	Pyralidae	Lepidoptera
Hairy caterpillar	*Metanastria hyrtaca* C.	Lasiocampidae	Lepidoptera
	Taragama siva Lef.	Lasiocampidae	Lepidoptera
Leaf caterpillar	*Actias selene* H.	Saturniidae	Lepidoptera
Hairy caterpillar	*Eupterote mollifera* Ik.	Bombycidae	Lepidoptera

Woolly bear	*Pericallia ricini* F.	Arctiidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
Blossom midge	*Stictodiplosis moringae* Mani	Cecidomyiidae	Diptera
Fruitfly	*Gitona distigma* M.	Drosophilidae	Diptera
Leaf defoliator	*Holotrichia insularis* Brenske	Melolonthidae	Coleoptera
Stem borer	*Coptops aedificator* F.	Cerambycidae	Coleoptera
	Diaxenopsis apomecynoides (B)	Cerambycidae	Coleoptera
Leaf weevil	*Myllocerus discolor* var. *variegatus* Boh.	Curculionidae	Coleoptera
	M. maculosus Desbi.	Curculionidae	Coleoptera
	M. tenuiclavis var. *inferior* Mshll.	Curculionidae	Coleoptera
	M. viridanus F.	Curculionidae	Coleoptera
	Ptochus ovulum Fst.	Curculionidae	Coleoptera

Raphanus sativus (RADISH)

Cotton whitefly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	Hemiptera
Plant lice	*Lapaphis erysimi* (Kalt.)	Aphididae	Hemiptera
Painted bug	*Bagrada cruciferarum* F.	Pentatomidae	Hemiptera
Leaf webber	*Crocidolomia pavonana* F.	Pyralidae	Lepidoptera
Cabbage borer	*Hellula undalis* Fb.	Pyralidae	Lepidoptera
	Spodoptera litura (F.)	Noctuidae	Lepidoptera
Pea leafminer	*Chromatomyia horticola* (Gour)	Agromyzidae	Diptera
Mustard sawfly	*Athalia proxima* (Klug)	Tenthredinidae	Hymenoptera
Flea beetle	*Chaetocnema basalis* Bally	Alticidae	Coleoptera
	Phyllotreta downsei B.	Alticidae	Coleoptera
	Apion sp.	Apionidae	Coleoptera

Sauropus androgynous (CHEKKURMANIS)

Cucurbit aphid	*Aphis malvae* Koch.	Aphididae	Hemiptera
Scale insect	*Saissetia hemisphaerica* (Targ.)	Coccidae	Hemiptera
Chillies thrips	*Scirtothrips dorsalis* Hood	Thripidae	Thysanoptera

Sechium edule (CHOW-CHOW)

Leafhopper	*Empoasca* sp.	Cicadellidae	Hemiptera
Cucurbit aphid	*Aphis malvae* Koch.	Aphididae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
	Saissetia hemisphaerica (Targ.)	Coccidae	Hemiptera
	Aonidiella orientalis (Newst.)	Diaspididae	Hemiptera
Leaf folder	*Glyphodes indica* (S.)	Pyralidae	Lepidoptera
Vine borer	*Apomecyna histrio* Fb.	Cerambycidae	Coleoptera
	A. pertigera Thoms.	Cerambycidae	Coleoptera
	A. saltator	Cerambycidae	Coleoptera

Solanum melongena (BRINJAL or EGG PLANT)

Rice smaller grasshopper	*Oxya nitidula* Willemse	Acrididae	Orthoptera
AK grasshopper	*Poekilocerus pictus* Fb.	Acrididae	Orthoptera

Cow bug	*Tricentrus bicolor* Dist.	Membracidae	Hemiptera
Leafhopper	*Empoasca devastans* Distant	Cicadellidae	Hemiptera
	Hishimonus phycitis (Dist.)	Cicadellidae	Hemiptera
Cotton white fly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	Hemiptera
Cotton aphid	*Aphis gossypii* G.	Aphididae	Hemiptera
Mealy bug	*Centrococcus insolitus* (Gr.)	Pseudococcidae	Hemiptera
	Aspidiotus destructor Sign.	Diaspididae	Hemiptera
	Aonidiella orientalis (Newst.)	Diaspididae	Hemiptera
	Chionaspis manni Gr.	Diaspididae	Hemiptera
	Cerococcus hibisci Green	Asterolecaniidae	Hemiptera
Black bug	*Anoplocnemis phasiana* F.	Coreidae	Hemiptera
Lace-wing bug	*Urentius hystricellus* (Richt.) *(= U. sentis)*	Tingidae	Hemiptera
Plant bug	*Coptosoma nazirae* A.	Plataspididae	Hemiptera
	Caliothrips indicus (Bag.)	Thripidae	Thysanoptera
Thrips	*Frankliniella schultzei* Trybom	Thripidae	Thysanoptera
	Scirtothrips dorsalis Hood	Thripidae	Thysanoptera
	Sericothrips solanifolii Shumsher	Thripidae	Thysanoptera
	Thrips apicatus Priesner	Thripidae	Thysanoptera
	T. tabaci Lind.	Thripidae	Thysanoptera
Budworm	*Phthorimaea blapsigona* M.	Gelechiidae	Lepidoptera
	P. operculella Z.	Gelechiidae	Lepidoptera
Stem borer	*Euzophera perticella* Rag.	Pyralidae	Lepidoptera
Shoot and fruit borer	*Leucinodes orbonalis* Guen.	Pyralidae	Lepidoptera
Leaf folder	*Phycita clientella* Z.	Pyralidae	Lepidoptera
Leaf webber	*Psara bipunctalis* F.	Pyralidae	Lepidoptera
Brinjal plume moth	*Pterophorus lienigianus* Z.	Pterophoridae	Lepidoptera
	Acherontia lachesis	Sphingidae	Lepidoptera
	A. styx Westw.	Sphingidae	Lepidoptera
	Pericallia ricini F.	Arctiidae	Lepidoptera
Cutworm	*Agrotis ipsilon* (Hufn.)	Noctuidae	Lepidoptera
Leaf roller	*Eublemma olivacea* W.	Noctuidae	Lepidoptera
Leaf caterpillar	*Plotheia nephelotis* Meyr.	Noctuidae	Lepidoptera
Hairy caterpillar	*Selepa celtis* M.	Noctuidae	Lepidoptera
	S. docilis B.	Noctuidae	Lepidoptera
	S. rabdota Hmpsn.	Noctuidae	Lepidoptera
	Spodoptera exigua (Hb.)	Noctuidae	Lepidoptera
	S. litura (F.)	Noctuidae	Lepidoptera
Green semilooper	*Thysanoplusia orichalcea* Fb.	Noctuidae	Lepidoptera
Tussock caterpillar	*Euproctis fraterna* M.	Lymantriidae	Lepidoptera
Blossom midge	*Asphondylia beguni* Mani	Cecidomyiidae	Diptera
Leaf miner	*Chromatomyia horticola* (Gour)	Agromyzidae	Diptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Fruitfly	*Bactrocera dorsalis* Hendel	Tephritidae	Diptera
	Solenopsis geminata Fb	Formicidae	Hymenoptera
White grub	*Anomala bengalensis* Blanch	Melolonthidae	Coleoptera
	Holotrichia consanguinea Blanch	Melolonthidae	Coleoptera

	H. insularis Brenske	Melolonthidae	Coleoptera
Flower beetle	*Oxycetonia versicolor* Fb.	Cetoniidae	Coleoptera
Spotted beetle	*Epilachna vigintioctopunctata* F.	Coccinellidae	Coleoptera
	Myllocerus discolor F.	Curculionidae	Coleoptera
Root grub	*M. subfasciatus* G.	Curculionidae	Coleoptera

Solanum tuberosum **(POTATO)**

Mole cricket	*Gryllotalpa africana* Pal.	Gryllotalpidae	Orthoptera
	Leptocentrus obliquus W.	Membracidae	Hemiptera
	Tricentrus bicolor Dist.	Membracidae	Hemiptera
Cotton leafhopper	*Empoasca devastans* Distant	Cicadellidae	Hemiptera
Cotton whitefly	*Bemisia tabaci* (Genn.)	Aleyrodidae	Hemiptera
Greenhouse whitefly	*Trialeurodes vaporariorum* (West.)	Aleyrodidae	Hemiptera
	Aphis gossypii G.	Aphididae	Hemiptera
	A. nasturtii (Kalt.)	Aphididae	Hemiptera
	Aluacorthum solani Kalt.	Aphididae	Hemiptera
	Macrosiphum euphorbiae (Thomas)	Aphididae	Hemiptera
Plant lice	*Myzus ornatus* Laing.	Aphididae	Hemiptera
	M. persicae (Sulz.)	Aphididae	Hemiptera
Tuber aphid	*Rhopalosiphoninus latysiphon* Davidson	Aphididae	Hemiptera
Root aphid	*R. rufiabdominalis* Sasaki	Pseudococcidae	Hemiptera
Tuber mealy bug	*Nipaecoccus vastator* (Maskell)	Pseudococcidae	Hemiptera
	Nezara viridula Linn.	Pentatomidae	Hemiptera
Thrips	*Caliothrips indicus* (Bagnall)	Thripidae	Thysanoptera
Potato tuber moth	*Phthorimaea operculella* Z.	Gelechiidae	Lepidoptera
Stem borer	*Euzophera perticella* Rag.	Pyralidae	Lepidoptera
	Leucinodes orbonalis Guen.	Pyralidae	Lepidoptera
Hairy caterpillar	*Olene mendosa* Wlk.	Lymantriidae	Lepidoptera
	Agrotis ipsilon (Hufn.)	Noctuidae	Lepidoptera
	A. segetum (Schiff.)	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
	Xestia c-nigrum (L.)	Noctuidae	Lepidoptera
Pea leaf miner	*Chromatomyia horticola* (Gour)	Agromyzidae	Diptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
	Dorylus labiatus S.	Formicidae	Hymenoptera
	D. orientalis W.	Formicidae	Hymenoptera
Wireworm	*Drasterius* sp.	Elateridae	Coleoptera
Spotted leaf beetle	*Henosepilachna vigintioctopunctata* F.	Coccinellidae	Coleoptera
	H. ocellata Redt.	Coccinellidae	Coleoptera
White grub	*Holotrichia coriacea* (Hope)	Melolonthidae	Coleoptera
Ground beetle	*Gonocephalum hoffmanseggi* St.	Tenebrionidae	Coleoptera
	Opatrum sp.	Tenebrionidae	Coleoptera
Flea beetle	*Chalaenosoma metallicum* F.	Alticidae	Coleoptera
	Luperomorpha bombayensis Jac.	Alticidae	Coleoptera
Leaf weevil	*Myllocerus subfasciatus* G.	Curculionidae	Coleoptera

Trichosanthes anguina (SNAKE GOURD)

Cucurbit aphid	*Aphis malvae* Koch	Aphididae	Hemiptera
Scale insect	*Saissetia hemisphaerica* (Targ.)	Coccidae	Hemiptera
Vine borer	*Melittia eurytion* Westw.	Sessiidae	Lepidoptera
Greasy cutworm	*Agrotis ipsilon* (Hufn.)	Noctuidae	Lepidoptera
Leaf semilooper	*Anadevidia peponis* F.	Noctuidae	Lepidoptera
Vine borer	*Apomecyna saltator* Fab.	Cerambycidae	Coleoptera
Fruitfly	*Bactrocera ciliatus* Loew.	Tephritidae	Diptera
	B. cucurbitae Coq.	Tephritidae	Diptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Leaf beetles	*Raphidopalpa foveicollis* (Lucas)	Gelerucidae	Coleoptera
	Aulacophora intermedia Jacoby	Gelerucidae	Coleoptera
Snakegourd weevil	*Baris trichosanthis* Sub.	Curculionidae	Coleoptera

Trichosanthes dioca (POINTED GOURD)

Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Vine borer	*Apomecyna saltator* Fab.	Cerambycidae	Coleoptera

FRUITS

Achras zapota (SAPOTA)

Mango hopper	*Amritodus atkinsoni* (L.)	Cicadellidae	Hemiptera
	Idioscopus clypealis (L.)	Cicadellidae	Hemiptera
	I. niveosparsus (L.)	Cicadellidae	Hemiptera
Castor whitefly	*Trialeurodes ricini* Misra	Aleyrodidae	Hemiptera
	Hemaspidoproctus cinereus Green	Margarodidae	Hemiptera
	Icerya sp.	Margarodidae	Hemiptera
	Walkeriana cinerea Gr.	Margarodidae	Hemiptera
	Phenacoccus iceryoides Gr.	Pseudococcidae	Hemiptera
	Planococcus citri (Riso)	Pseudococcidae	Hemiptera
	P. lilacinus Ckll.	Pseudococcidae	Hemiptera
	Coccus longulum (Dougl.)	Coccidae	Hemiptera
	Chloropulvinaria psidii (Mask.)	Coccidae	Hemiptera
	Saissetia oleae Ber.	Coccidae	Hemiptera
	Aspidiotus transparens Gr.	Diaspididae	Hemiptera
Green planthopper	*Flata ocellata* Fb.	Flatidae	Hemiptera
Flower thrips	*Frankliniella schultzei* Trybom	Thripidae	Thysanoptera
Budworm	*Anarsia* sp.	Gelechiidae	Lepidoptera
Flower bud borer	*Chelaria* sp.	Gelechiidae	Lepidoptera
	Lecithocera metacausta Meyr.	Gelechiidae	Lepidoptera
	Rhodoneura myrtaea Drury	Thyrididae	Lepidoptera
Bud borer	*Acrobasis pomonella*	Pyralidae	Lepidoptera
Leaf webber	*Nephopetryx eugraphella* R.	Pyralidae	Lepidoptera
Seed borer	*Trymalitis margarias* Meyr.	Tortricidae	Lepidoptera
Hairy caterpillar	*Metanastria hyrtaca* C.	Lasiocampidae	Lepidoptera

Fruit borer	*Deudorix (= Virachola) isocrates* Fb.	Lycaenidae	Lepidoptera
Fruitfly	*Bactrocera dorsalis* Hendel	Tephritidae	Diptera
	B. zonatus Saund.	Tephritidae	Diptera

Anacardium occidentale (CASHEW)

Plant lice	*Toxoptera odinae* V & G	Aphididae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
	Plancoccus lilacinus Ckll.	Pseudococcidae	Hemiptera
	Monophlebus sp.	Margarodidae	Hemiptera
	Ceroplastes floridensis C.	Coccidae	Hemiptera
	Coccus hesperidum L.	Coccidae	Hemiptera
	Lacanium latioperculum G.	Coccidae	Hemiptera
	Diaspis sp.	Diaspididae	Hemiptera
	Helopeltis antonii S.	Miridae	Hemiptera
	H. theivora	Miridae	Hemiptera
	Pachypeltis massarum	Miridae	Hemiptera
	Catacanthus sp.	Pentatomidae	Hemiptera
	Paradasynus sp. (*rostratus* Dist?)	Coreidae	Hemiptera
Thrips	*Retithrips syriacus* M.	Thripidae	Thysanoptera
	Rhipiphorothrips cruentatus Hood	Thripidae	Thysanoptera
	Rhynchothrips raoensis R.	Phlaeothripidae	Thysanoptera
	Selenothrips rubrocinctus G.	Thripidae	Thysanoptera
Shoot tip & inflorescence caterpillar	*Chelaria haligramma* M.	Gelechiidae	Lepidoptera
Leaf miner	*Acrocercops syngramma* M.	Gracillariidae	Lepidoptera
Bark bordr	*Indarbela tetraonis* M.	Metarbelidae	Lepidoptera
Castor slug caterpillar	*Latoia lepida* C.	Limacodiidae	Lepidoptera
	Argyroploce tonsoria M.	Eucosmidae	Lepidoptera
Fig moth	*Cadra cautella* (Wlk.)	Pyralidae	Lepidoptera
Leaf webber	*Macalla eumictalis* Hmpsn.	Pyralidae	Lepidoptera
Shoot and blossom webber	*Lamida monousalis* Walk.	Pyralidae	Lepidoptera
Cashew apple borer	*Nephopteryx* sp.	Pyralidae	Lepidoptera
Indian meal moth	*Plodia interpunctella* H.	Pyralidae	Lepidoptera
	Syllepte (=Sylepta) aurantiacollis F.	Pyralidae	Lepidoptera
Cashew apple & nut borer	*Thylocoptila panrosema* M.	Pyralidae	Lepidoptera
Hairy caterpillar	*Metanastria hyrtaca* C.	Lasiocampidae	Lepidoptera
Tassar silk moth	*Antheraea paphia* B.	Saturniidae	Lepidoptera
Leaf caterpillar	*Cricula trifenestrata* H.	Saturniidae	Lepidoptera
Looper caterpillar	*Oenospila flavifuscata* W.	Geometridae	Lepidoptera
Butterfly	*Symphaedra (=Euthalia) nais* (F.)	Nymphalidae	Lepidoptera
Shoot webber	*Anigraea albomaculata* Hamp.	Noctuidae	Lepidoptera
Tender leaf feeder	*Penicillaria jocosatrix* Guen.	Noctuidae	Lepidoptera
	Orthaga exvinacea M.	Noctuidae	Lepidoptera
Fruit sucking moth	*Othreis fullonica* L.	Noctuidae	Lepidoptera
Fruit sucking moth	*O. homaena*	Noctuidae	Lepidoptera

Fruit sucking moth	*O. materna* L.	Noctuidae	Lepidoptera
Fruit sucking moth	*Rhytia hypermenestra*	Noctuidae	Lepidoptera
Tussock caterpillar	*Porthesia scintillans* W.	Lymantriidae	Lepidoptera
	Camponotus sp.	Formicidae	Hymenoptera
Red ant	*Oecophylla smaragdina* F.	Formicidae	Hymenoptera
"Cadelle" beetle	*Tenebroides mauritanicus* L.	Ostomatidae	Coleoptera
White grub	*Holotrichia* sp.	Melolonthidae	Coleoptera
Copra beetle	*Necrobia rufipes* DeGeer	Cleridae	Coleoptera
Saw-toothed beetle	*Oryazephilus surinamensis* L.	Tenebrionidae	Coleoptera
Red flour beetle	*Tribolium castaneum* Hbst.	Tenebrionidae	Coleoptera
Stem borer	*Plocaederus consocius* P.	Cerambycidae	Coleoptera
	P. ferrugineus L.	Cerambycidae	Coleoptera
	Prionoma atratum G.	Cerambycidae	Coleoptera
Stem girdler	*Sthenias grisator* (Fb.)	Cerambycidae	Coleoptera
Leaf beetle	*Monolepta longitarsus* J.	Galerucidae	Coleoptera
Shoot weevil	*Apion ampulum* Fst.	Apionidae	Coleoptera
Leaf twister	*Apoderus tranquebaricus* F.	Curculionidae	Coleoptera
	Amblyrhinus poricollis B.	Curculionidae	Coleoptera
	Myllocerus discolor B.	Curculionidae	Coleoptera
	M. viridanus F.	Curculionidae	Coleoptera

Ananas sativus (PINE APPLE)

Pine apple mealy bug	*Dysmicoccus brevipes* (Ckll.)	Pseudococcidae	Hemiptera
Coconut black beetle	*Oryctes rhinoceros* Linn.	Dynastidae	Coleoptera

Anona squamosa (CUSTARD APPLE)

Cow bug	*Otinotus oneratus* W.	Membracidae	Hemiptera
	Aleurocanthus rugosa Singh	Aleyrodidae	Hemiptera
Spiralling whitefly	*Aleurodicus dispersus* Russell	Aleyrodidae	Hemiptera
White fly	*Dialeuropora decempuncta* (Q. & B.)	Aleyrodidae	Hemiptera
	Trialeurodes ricini Misra	Aleyrodidae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
	Planococcus lilacinus Ckll.	Pseudococcidae	Hemiptera
	Ceroplastes floridensis Const.	Coccidae	Hemiptera
	Saissetia hemisphaerica (Targ.)	Coccidae	Hemiptera
Lac insect	*Laccifer communis* Mahdihassan	Lacciferidae	Hemiptera
Castor thrips	*Retithrips syriacus* (Mayet)	Thripidae	Thysanoptera
Grapevine thrips	*Rhipiphorothrips cruentatus* Hood	Thripidae	Thysanoptera
	Pyroderces falcetalla St.	Cosmopterygidae	Lepidoptera
Fruitfly	*Bactrocera persicae* B.	Tephritidae	Diptera
	B. zonatus (Saund)	Tephritidae	Diptera
Seed scolytid	*Coccotrypes carpophagus* Horn	Scolytidae	Coleoptera

Artocarpus heterophyllus (JACK)

Spittle bug	*Clovia lineaticollis* D.	Cercopidae	Hemiptera
Jack spittle bug	*Cosmoscarta relata* D.	Cercopidae	Hemiptera

Spittle bug	*Ptyelus* sp.	Cercopidae	Hemiptera
Whitefly	*Aleurotrachelus caerulescens* Singh	Aleyrodidae	Hemiptera
	Pealius schimae Takahashi	Aleyrodidae	Hemiptera
Jack aphid	*Greenidia artocarpi* (West.)	Aphididae	Hemiptera
Black aphid	*Toxoptera aurantii* (Bd F.)	Aphididae	Hemiptera
Fluted scale	*Icerya aegyptiaca* (Dougl.)	Margarodidae	Hemiptera
Mango scale	*Drosicha stebbingi* (Green)	Margarodidae	Hemiptera
Tailed mealy bug	*Ferrisia virgata* (Ckil.)	Pseudococcidae	Hemiptera
	Nipaecoccus vastator (Mask.)	Pseudococcidae	Hemiptera
	Ceroplastes rubens M.	Coccidae	Hemiptera
	Aspidiotus triglandulosus Gr.	Diaspididae	Hemiptera
	Hemiberlesia lataniae Sign.		
	Stephanitis charieis D.& M.	Tingidae	Thysanoptera
Leaf thrips	*Pseudodendrothrips dwivarna* (R.& M.)	Thripidae	Thysanoptera
Bark borer	*Indarbela tetraonis* M.	Metarbelidae	Lepidoptera
	Conogethes punctiferalis Guen.	Pyralidae	Lepidoptera
Laef caterpillar	*Glyphodes bivitralis* Guen.	Pyralidae	Lepidoptera
Shoot borer	*G. caesalis* W.	Pyralidae	Lepidoptera
Hairy caterpillar	*Perina nuda*	Lymantriidae	Lepidoptera
Decaying fruit midge	*Camptomyia artocarpi* Nayar.	Cecidomyiidae	Diptera
	Rubsaamenia artocarpi Nayar	Cecidomyiidae	Diptera
Mango stem borer	*Batocera rufomaculata* DeG.	Cerambycidae	Coleoptera
	Glenia belli G.	Cerambycidae	Coleoptera
Bud weevil	*Ochyromera artocarpi* M.	Curculionidae	Coleoptera

Citrus sp. (CITRUS)

'AK' Grasshopper	*Poekilocerus pictus* (Fb.)	Acrididae	Orthoptera
Shoot cricket	*Brachytrypes portentosus* L.	Gryllidae	Orthoptera
	Oxyrhachis tarandus	Membracidae	Hemiptera
	Tricentrus bicolor Dist.	Membracidae	Hemiptera
Citrus psyllid	*Diaphorina citri* K.	Psyllidae	Hemiptera
	Aleurocanthus husaini Corbett	Aleyrodidae	Hemiptera
	A. citriperdus Q.& B.	Aleyrodidae	Hemiptera
	A. nagpurensis	Aleyrodidae	Hemiptera
	A. woglumi Ashby	Aleyrodidae	Hemiptera
	Aleuroclava (= *Aleurotuberculatus*) *murrayae* (Singh.)	Aleyrodidae	Hemiptera
	Aleurolobus citrifolii Corbett	Aleyrodidae	Hemiptera
	A. marlatti Quaintance	Aleyrodidae	Hemiptera
	Dialeurodes citri Ashmead	Aleyrodidae	Hemiptera
	Dialeurolonga cephalidistinctus D.	Aleyrodidae	Hemiptera
	D. elongata (Dozier)	Aleyrodidae	Hemiptera
	Aphis taversi DG	Aphididae	Hemiptera
	Toxoptera aurantii (Bd F)	Aphididae	Hemiptera
	T. citricidus K.	Aphididae	Hemiptera
Mango scale	*Drosicha stebbingi* (Gr.)	Margarodidae	Hemiptera

	Hemaspidoproctus cinereus Gr.	Margarodidae	Hemiptera
Cottony cushion scale	*Icerya aegyptiaca* (Douglas)	Margarodidae	Hemiptera
	I. purchasi Mask.	Margarodidae	Hemiptera
	Labioproctus polei (Green)	Margarodidae	Hemiptera
	Monophlebus sp.	Margarodidae	Hemiptera
	Walkeriana cinerea Gr.	Margarodidae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
Mealy bug	*Maconellicoccus hirsutus* (Green)	Pseudococcidae	Hemiptera
	Phenacoccus iceryoides Gr.	Pseudococcidae	Hemiptera
	Orthezia insignis D.	Ortheziidae	Hemiptera
	Nipaecoccus vastator (Mask.)	Pseudococcidae	Hemiptera
	Planococcus citri (Risso)	Pseudococcidae	Hemiptera
	Pseudococcus citrulus Green	Pseudococcidae	Hemiptera
	Rastrococcus sp. nr. *iceryoides* (Green)	Pseudococcidae	Hemiptera
	Aonidiella aurantii (Mask.)	Diaspididae	Hemiptera
	Aspidiotus transparens Gr.	Diaspididae	Hemiptera
	Chionaspis pusae Gr.	Diaspididae	Hemiptera
	Chrysomphalus ficus Ashm.	Diaspididae	Hemiptera
	Fiorinia sp.	Diaspididae	Hemiptera
	Mytilococcus (= Lepidosaphes) beckii N.	Diaspididae	Hemiptera
	M. gloveri (Packard)	Diaspididae	Hemiptera
	Parlatoria zizyphus L.	Diaspididae	Hemiptera
	Pinnaspis aspidistrae Sign.	Diaspididae	Hemiptera
	Ceroplastes floridensis Comst.	Coccidae	Hemiptera
	C. rubens Maskell	Coccidae	Hemiptera
	Coccus hesperidum L.	Coccidae	Hemiptera
	C. viride (Gr.)	Coccidae	Hemiptera
	Lecanium discrepans Gr.	Coccidae	Hemiptera
	Paracoccus sp.	Coccidae	Hemiptera
	Parasaissetia nigra (Nietn.)	Coccidae	Hemiptera
Mealy scale	*Pulvinaria cellulosa* Gr.	Coccidae	Hemiptera
	Saissetia hemisphaerica (Targ.)	Coccidae	Hemiptera
	Vinsonia stellifera (Westwood)	Coccidae	Hemiptera
	Dasynus antennatus V.	Coreidae	Hemiptera
Spittle bug	*Cosmoscarta fumeralis* Butler	Cercopidae	Hemiptera
	Antestiopsis cruciata (Fb.)	Pentatomidae	Hemiptera
	Spilostethus pandurus (Scop.)	Lygaeidae	Hemiptera
	Cappoea taprobanensis D.	Lygaeidae	Hemiptera
	Rhynchocoris humeralis (Thunb.)	Lygaeidae	Hemiptera
	Vitellus orientalis D.	Lygaeidae	Hemiptera
Flower thrips	*Ramaswamiahielia subnudula* (Karny)	Thripidae	Thysanoptera
	Thrips flavus Schrank	Thripidae	Thysanoptera
	T. hawaiiensis (Morgan)	Thripidae	Thysanoptera
	T. nilgiriensis R.	Thripidae	Thysanoptera

Leafroller	*Psorosticha* (=*Tonica) zizyphi* S.	Depressariidae	Lepidoptera
Citrus leaf miner	*Phyllocnistis citerella* S.	Gracillariidae	Lepidoptera
Bark borer	*Indarbela tetraonis* M.	Metarbelidae	Lepidoptera
	I. quadrinotata W.	Metarbelidae	Lepidoptera
Slug caterpillar	*Narosa propolia* Hmpsn.	Limacodiidae	Lepidoptera
	Conogethes punctiferalis (Guen.)	Pyralidae	Lepidoptera
Shoot butterfly	*Chilades laius* C.	Lycaenidae	Lepidoptera
Citrus butterfly	*Papilio demoleus* L.	Papilionidae	Lepidoptera
	P. polymnestor Gram.	Papilionidae	Lepidoptera
	P. poytes L.	Papilionidae	Lepidoptera
Fruit sucking moth	*Achaea janata* Linn.	Noctuidae	Lepidoptera
	Anua coronata Fb.	Noctuidae	Lepidoptera
	A. mejanesi Guen	Noctuidae	Lepidoptera
	A. tirrhaca Cram.	Noctuidae	Lepidoptera
	Calpe emarginata Fb.	Noctuidae	Lepidoptera
	C. ophideroides Gluenee	Noctuidae	Lepidoptera
	Ercheia diversipennis Wlk.	Noctuidae	Lepidoptera
	E. cyllaria (Cramer)	Noctuidae	Lepidoptera
	Lagoptera dotata Fb.	Noctuidae	Lepidoptera
	L. honesta Hubn.	Noctuidae	Lepidoptera
	L. submira Wlk.	Noctuidae	Lepidoptera
	Mocis ftugalis Fb.	Noctuidae	Lepidoptera
	Nyctipao hieroglyphicus (Drury)	Noctuidae	Lepidoptera
	Othreis homaena (=*ancilla* Cram.)	Noctuidae	Lepidoptera
	P. fullonica Linn.	Noctuidae	Lepidoptera
	O. materna Linn.	Noctuidae	Lepidoptera
	Paralellia algira Linn.	Noctuidae	Lepidoptera
	Pericyma glaucinans Guen.	Noctuidae	Lepidoptera
	Polydesma quenavadi Guen.	Noctuidae	Lepidoptera
	Rhytia hypermenestra	Noctuidae	Lepidoptera
	Simplicia robustalis G.	Noctuidae	Lepidoptera
Tussock caterpillar	*Euproctis fraterna* M.	Lymantriidae	Lepidoptera
Blossom midge	*Dasineura citri* Gr. & Pr.	Cecidomyiidae	Diptera
Fruitfly	*Bactrocera dorsalis* Hendel.	Tephritidae	Diptera
	B. hagenii DM.	Tephritidae	Diptera
Red ant	*Oecophylla smaragdina* Fb.	Formicidae	Hymenoptera
	Aserica nilgiriensis Shp.	Melolonthidae	Coleoptera
June beetle	*Ectinohoplia nitidivetitris* Arrow	Melolonthidae	Coleoptera
	Holotrichia repetita Sharp	Melolonthidae	Coleoptera
	Schizonycha ruficollis F.	Melolonthidae	Coleoptera
	Agrilus grisator Kerremans	Buprestidae	Coleoptera
	A. mediocris Kerremans	Buprestidae	Coleoptera
	Belinota prasina Th.	Buprestidae	Coleoptera
Orange borer	*Chelidonium cinctum* G.	Cerambycidae	Coleoptera
	Chloridolum alcamene T.	Cerambycidae	Coleoptera
	Demonax balvi Pasc.	Cerambycidae	Coleoptera
	Ginatholea eburifera (Thomson)	Cerambycidae	Coleoptera

Trunk borer	*Anoplophora versteegi* Rits.	Cerambycidae	Coleoptera
Lesser orange borer	*Obera manalorensis*	Cerambycidae	Coleoptera
	Peltotrachelus pubes Forster	Cerambycidae	Coleoptera
	Stromatium barbatum (Fb.)	Cerambycidae	Coleoptera
	Amblyrrhinus poricollis Boh.	Curculionidae	Coleoptera
	Astycus chrysochlorus Wied.	Curculionidae	Coleoptera
	A. immunis (Walker)	Curculionidae	Coleoptera
	Hypomeces squamosus (Fb.)	Curculionidae	Coleoptera
Leaf weevil	*Myllocerus dentifer* Fb.	Curculionidae	Coleoptera
	M. evasus M.	Curculionidae	Coleoptera
Flower beetle	*Heterorrhina elegans* (Fb.)	Cetoniidae	Coleoptera
	Oxycetonia histrio (Oliv.)	Cetoniidae	Coleoptera
	O. jucunda Feld.	Cetoniidae	Coleoptera
Leaf beetle	*Colasposoma aureovittatum* Baly.	Eumolpidae	Coleoptera
	C. semicostatum Jacoby	Eumolpidae	Coleoptera
Black & red leaf miner	*Throscoryssa citri* Maulik	Chrysomelidae	Coleoptera
	Adoretosoma citricola Ohavs	Rutelidae	Coleoptera
	Singhara tenella Blanchard	Rutelidae	Coleoptera
Bark beetle	*Xyleborus affinis* Eich.	Scolytidae	Coleoptera
	X. testaceus (Walker)	Scolytidae	Coleoptera
Stag beetle	*Prosopocoilus spencei* (Hope)	Lucanidae	Coleoptera

Cydonia oblonga (QUINCE)

	Eulecanium corylii L.	Coccidae	Hemiptera
	Eucosma ocellana Schiff.	Eucosmidae	Lepidoptera
	Cacoecia sarcostega Meyr.	Torticidae	Lepidoptera
Fruitfly	*Bactrocera dorsalis* Hendel	Tephritidae	Diptera

Emblica officinalis (AMLA or AONLA)

	Cerciaphis emblica Patel & Kulkarny	Aphididae	Hemiptera
	Schoutedonia emblica Patel & Kulkarny	Aphididae	Hemiptera
	Setaphis bougainvilliae T.	Aphididae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
	Nipaecoccus vastator (Mask.)	Pseudococcidae	Hemiptera
	Scutellera nobilis F.	Scutelleridae	Hemiptera
Leaflet twister	*Caloptilia acidula* (Meyr.)	Gracillariidae	Lepidoptera
Stem gall	*Betonsa stylophora* Swinh.	Therevidae	Lepidoptera
Bark borer	*Indarbela tetraonis* M.	Metarbelidae	Lepidoptera
Bark borer	*I. quadrinotata* Wlk.	Metarbelidae	Lepidoptera
Pomegranate butterfly	*Deudorix isocrates* Fb.	Lycaenidae	Lepidoptera
Hairy caterpillar	*Selepa celtis* M.	Noctuidae	Lepidoptera
Leaf gall	*Asphondylia phyllanthi* Felt	Cecidomyiidae	Diptera

Eriobotrya japonica (LOQUAT)

	Aphis malvae (Koch.)	Aphididae	Hemiptera
Scale insect	*Saissetia hemisphaerica* (Targ.)	Coccidae	Hemiptera
	Deudorix isocrates Fb.	Lycaenidae	Lepidoptera
Fruitfly	*Bactrocera dorsalis* Hendel	Tephritidae	Diptera
Leaf cutter bee	*Megachile* sp.	Apidae	Hymenoptera
	Adoretus sp.	Rutelidae	Coleoptera
	Myllocerus discolor B.	Curculionidae	Coleoptera
	M. laetivirens Mshll.	Curculionidae	Coleoptera

Feronia elephantum (WOOD APPLE)

Mealy bug	*Nipaecoccus vastator* (Mask.)	Pseudococcidae	Hemiptera
	Aleurolobus orientalis David & Jesudasan	Aleyrodidae	Hemiptera
	Latoia lepida C.	Limacodiidae	Lepidoptera
	Argyroploce illepidae Butl.	Eucosmidae	Lepidoptera
Fruit borer	*Euzophera plubeifasciella* Hmpsn.	Pyralidae	Lepidoptera
	Deudorix isocrates Fb.	Lycaenidae	Lepidoptera
	Papilio demoleus Linn.	Papilionidae	Lepidoptera

Ficus carica (FIG)

'AK' Grasshopper	*Poekilocerus pictus* (Fb.)	Acrididae	Orthoptera
Spittle bug	*Cosmoscarta niteara* D.	Cercopidae	Hemiptera
	Taiwanaleyrodes indica Singh	Aleyrodidae	Hemiptera
	Kolla diaphana Dist.	Cicadellidae	Hemiptera
	Erythroneura sp.	Cicadellidae	Hemiptera
	Nirvana sp.	Cicadellidae	Hemiptera
	Drosicha stebbingi (Gr.)	Margarodidae	Hemiptera
Coccid	*Pseudococcus lilacinus* Ckll.	Pseudococcidae	Hemiptera
	Ceroplastes actiniformis Gr.	Coccidae	Hemiptera
	Coccus discrepans	Coccidae	Hemiptera
	Lecanium remakrishnae G.	Coccidae	Hemiptera
	Saissetia oleae B.	Coccidae	Hemiptera
	Hemiberlesia lataniae Sign.	Diaspididae	Hemiptera
	Aspidiotus transparens Gr.	Diaspididae	Hemiptera
	C. cydoniae C.	Diaspididae	Hemiptera
	Leucaspis riccae Targ.	Diaspididae	Hemiptera
	Parlatoria oleae (Colv.)	Diaspididae	Hemiptera
	Riptortus linearis (Fb.)	Coreidae	Hemiptera
Thrips	*Gigantothrips elegans* Z.	Thripidae	Thysanoptera
	Phycodes radiata Ochs.	Glyphipterygidae	Lepidoptera
	P. minor M.	Glyphipterygidae	Lepidoptera
	Glyphodes phyloalis W.	Pyralidae	Lepidoptera
	G. stolalis G.	Pyralidae	Lepidoptera
Indian meal moth	*Plodia interpunctella* Hubn.	Pyralidae	Lepidoptera

Wild silkworm	*Ocinara varians* W.	Bombycidae	Lepidoptera
Cutworm	*Agrotis ipsilon* (Hufn.)	Noctuidae	Lepidoptera
	A. segetum (Schiff)	Noctuidae	Lepidoptera
	Xestia c-nigrum (L.)	Noctuidae	Lepidoptera
Hairy caterpillar	*Selepa celtis* M.	Noctuidae	Lepidoptera
Tussock caterpillar	*Perina nuda* F.	Lymantriidae	Lepidoptera
	Asota alcifrons (C.)	Hypsidae	Lepidoptera
	A. ficus F.	Hypsidae	Lepidoptera
Fig midge	*Anjeerodiplosis peshawarensis* Mani	Cecidomyiidae	Diptera
Fruitfly	*Bactrocera dorsalis* Hendel	Tephritidae	Diptera
	B. zonatus Saund.	Tephritidae	Diptera
Foliage beetle	*Adoretus* spp.	Rutelidae	Coleoptera
Apple borer	*Apriona cinerea* Chev.	Cerambycidae	Coleoptera
Mango stemborer	*Batocera rufomaculata* DeG	Cerambycidae	Coleoptera
Stemborer	*Olenecamptus bilobus* F.	Cerambycidae	Coleoptera
	Haltica caerulescens Baly.	Alticidae	Coleoptera
	Myllocerus blandus	Curculionidae	Coleoptera
	M. maculosus Desbr.	Curculionidae	Coleoptera

Garcinia mangostana (MANGOSTEEN)

Leaf defoliator	*Lophoptera* sp.	Noctuidae	Lepidoptera

Juglans regia (WALNUT)

Walnut aphid	*Callaphis juglandis* Kalt.	Callaphididae	Hemiptera
Aphid	*Chromaphis juglandicola* G.	Callaphididae	Hemiptera
	Actias selene Hb.	Saturniidae	Lepidoptera
Tent caterpillar	*Malocosoma indica* Wlk.	Lasiocampidae	Lepidoptera
	Adoretus versutus Harold	Rutelidae	Coleoptera
	Anomala rugosa Arrow	Rutelidae	Coleoptera
	Brahmina coriacea Hope	Melolonthidae	Coleoptera
	Serica sp.	Melolonthidae	Coleoptera
	Apion sp.	Apionidae	Coleoptera
Walnut weevil	*Alcidodes porrectirostris* Mshil.	Curculionidae	Coleoptera

Litchi chinensis (LITCHI)

Blackfly	*Aeurocanthus husaini* Corbett	Aleyrodidae	Hemiptera
Whitefly	*Dialeurolonga cephalidistinctus* D.	Aleyrodidae	Hemiptera
	D. elongata Dozier	Aleyrodidae	Hemiptera
Aphid	*Toxoptera aurantii* (BdF)	Aphididae	Hemiptera
	Kerria albizziae (Gr.)	Kerridae	Hemiptera
Cow bug	*Gargara varicolor* Stal.	Membracidae	Hemiptera
Grey armoured scale	*Thysanofiorinia leeli* Williams	Diaspididae	Hemiptera
	Chrysocoris stollii (Wolff.)	Scutelleridae	Hemiptera
	Halys dentatus Fabr.	Pentatomidae	Hemiptera
	Tessaratoma javanica Thunb.	Pentatomidae	Hemiptera

Leaf thrips	*Dolichothrips indicus* Hood	Phlaeothripidae	Thysanoptera
Flower thrips	*Megalurothrips usitatus* (Begn.)	Thripidae	Thysanoptera
	Cryptophleba carpophaga Wlsm.	Cosmopterygidae	Lepidoptera
Leaf miner	*Acrocercops cramerella* Snell.	Gracillariidae	Lepidoptera
Bark borer	*Indarbela tetraonis* M.	Metarbelidae	Lepidoptera
Leafroller	*Argyroploce aprobola* Meyr.	Eucosmidae	Lepidoptera
	A. erotias Meyr.	Eucosmidae	Lepidoptera
	A. illepida Meyr.	Eucosmidae	Lepidoptera
	A. leucaspis Meyr.	Eucosmidae	Lepidoptera
	Cacoecia epicytra Meyr.	Tortricidae	Lepidoptera
Slug caterpillar	*Latoia lepida* C.	Limacodiidae	Lepidoptera
Fruit borer	*Deudorix isocrates* F.	Lycaenidae	Lepidoptera
	Rapala sp.	Lycaenidae	Lepidoptera
Tussock caterpillar	*Lymantria mathura* Moore	Lymantriidae	Lepidoptera
	Cryptocephalus insubidus Saff.	Cryptocephalidae	Coleoptera
	Diapromorpha quadripunctata J.	Galeuricidae	Coleoptera
	Nodostoma fulvicorne J.	Galeuricidae	Coleoptera
Leaf cutting weevil	*Apoderus blandus* Faust	Curculionidae	Coleoptera
Weevil	*Myllocerus delecatalus* B.	Curculionidae	Coleoptera
Weevil	*M. dorsatus* F.	Curculionidae	Coleoptera
Weevil	*M. maculosus* D.	Curculionidae	Coleoptera
Leaf weevil	*Ptochus* sp.	Curculionidae	Coleoptera

Malpighia punicifolia **(WEST INDIAN CHERRY)**

Grasshopper	*Euprepocnemis pulchera* Bol.	Acrididae	Orthoptera
Wingless grasshopper	*Neorthacris simulans* B.	Acrididae	Orthoptera
Cow bug	*Otinotus lignicola* Buckt.	Membracidae	Hemiptera
Plant lice	*Aphis craccivora* Koch.	Aphididae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
Fluted scale	*Icerya aegyptiaca* (Dougl.)	Pentatomidae	Hemiptera
Stink bug	*Plautia fimbriata* F.	Margarodidae	Hemiptera
Laef folder	*Cacoecia epicyrta* Meyr.	Tortricidae	Lepidoptera
Skipper	*Badamia exclamationis* F.	Hesperiidae	Lepidoptera
Semilooper	*Eublemma abrupta* Wlk.	Noctuidae	Lepidoptera
Tussock catefpillar	*Euproctis fraterna* M.	Lymantriidae	Lepidoptera
	Orgyia postica (Wlk.)	Lymantriidae	Lepidoptera
	Porthesia scintillans Wlk.	Lymantriidae	Lepidoptera
Leaf weevil	*Myllocerus discolor* F.	Curculionidae	Coleoptera
	M. maculosus Desbr.	Curculionidae	Coleoptera
	M. viridanus F.	Curculionidae	Coleoptera

Mangifera indica **(MANGO)**

Grasshopper	*Aularches miliaris* Linn.	Acrididae	Orthoptera
	Gryllus viator	Gryllidae	Orthoptera
White ant	*Neotermes gardneri* Synder	Kalotermitidae	Isoptera

	Coptotermes gestroi Wasm.	Rhinotermitidae	Isoptera
	Odontotermes obesus (Ram.)	Termitidae	Isoptera
	O. wallonensis (Wasm.)	Termitidae	Isoptera
	Trinervitermes biformis	Termitidae	Isoptera
	Leptocentrus obliquus W.	Membracidae	Hemiptera
	Oxyrhachis tarandus Fabr.	Membracidae	Hemiptera
	Tricentrus bicolor Dist.	Membracidae	Hemiptera
Leaf hopper	*Amrasca splendens* Ghauri	Cicadellidae	Hemiptera
Mango hopper	*Amritodus atkinsoni* (L.)	Cicadellidae	Hemiptera
	A. brevistylus Viraktamath	Cicadellidae	Hemiptera
	Busoniomimus manjunathi Viraktamath	Cicadellidae	Hemiptera
	Idioscopus anasuyae Viraktamath	Cicadellidae	Hemiptera
	I. clypealis (L.)	Cicadellidae	Hemiptera
	I. decoratus Viraktamath	Cicadellidae	Hemiptera
	I. jayashriae Viraktamath	Cicadellidae	Hemiptera
	I. nagpurensis (Pruthi)	Cicadellidae	Hemiptera
	I. niveosparsus (L.)	Cicadellidae	Hemiptera
	I. spectabilis Viraktamath	Cicadellidae	Hemiptera
Mango gall psyllid	*Apsylla cistellata* Buckton	Psyllidae	Hemiptera
	Arytaina obscura Crawford	Psyllidae	Hemiptera
	Leuronotata minuta (Crawford)	Psyllidae	Hemiptera
	Pauropsylla brevicornis Crawford	Psyllidae	Hemiptera
	P. maculata	Psyllidae	Hemiptera
	P. nigra Crawford	Psyllidae	Hemiptera
Mango aleyrodid	*Aleurocanthus mangiferae* Q.& B.	Aleyrodidae	Hemiptera
	Toxoptera odinae V. & G.	Aphididae	Hemiptera
	Drosicha stebbingi (Gr.)	Margarodidae	Hemiptera
	Icerya pulcher (Leon.)	Margarodidae	Hemiptera
	L minor Gr.	Margarodidae	Hemiptera
	L seychellarum Westw.	Margarodidae	Hemiptera
	Kerria lacca (Kerr.)	Kerridae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
	Labioproctus polei (Green)	Pseudococcidae	Hemiptera
	Phenacoccus ballardi Newst.	Pseudococcidae	Hemiptera
	P. iceryoides Gr.	Pseudococcidae	Hemiptera
	P. mangiferae Gr.	Pseudococcidae	Hemiptera
	Planococcus citri (Risso)	Pseudococcidae	Hemiptera
	P. robustus E & C	Pseudococcidae	Hemiptera
	Pseudococcus adonidum Linn	Pseudococcidae	Hemiptera
	P. lilacinus (Ckll.)	Pseudococcidae	Hemiptera
	Rastrococcus iceryoides Green	Pseudococcidae	Hemiptera
	Ceroplastes ceriferus And.	Coccidae	Hemiptera
	C. floridensis Comst.	Coccidae	Hemiptera
Green shield scale	*C. polygonata* (Ckll.)	Coccidae	Hemiptera
	C. pseudoceriferus Gr.	Coccidae	Hemiptera
	Chloropulvinaria psidii (Mask.)	Coccidae	Hemiptera
	Coccus colemani C & K.	Coccidae	Hemiptera

	C. hesperidum L.	Coccidae	Hemiptera
	Lecanium acutissimum Gr.	Coccidae	Hemiptera
	L. adersi Newst.	Coccidae	Hemiptera
	L. bicruciatum Gr.	Coccidae	Hemiptera
	L. latioperculam Gr.	Coccidae	Hemiptera
	L. mangiferae Gr.	Coccidae	Hemiptera
	Pulvinaria cellulose Gr.	Coccidae	Hemiptera
	P. ixorae Green	Coccidae	Hemiptera
	P. pergandei Comst.	Coccidae	Hemiptera
	P. polygonata Ckll.	Coccidae	Hemiptera
	Saissetia hemisphaerica (Targ.)	Coccidae	Hemiptera
	Aspidiotus destructor Sign.	Diaspididae	Hemiptera
	A. dictyospermi Morg.	Diaspididae	Hemiptera
	Aspidiotus rosae Mask.	Diaspididae	Hemiptera
	A. trilobitiformis Gr.	Diaspididae	Hemiptera
	Aulacaspis rosae Bch.	Diaspididae	Hemiptera
	Chionaspis dilatata Gr.	Diaspididae	Hemiptera
	C. vitis Gr.	Diaspididae	Hemiptera
	Chrysomphalus ficus Ashm.	Diaspididae	Hemiptera
	Diaspis barberi Gr.	Diaspididae	Hemiptera
	D. mangiferae Newst.	Diaspididae	Hemiptera
	D. rosea Bouche	Diaspididae	Hemiptera
	Lepidosaphes gloverii Rack.	Diaspididae	Hemiptera
	L. tapleyi Williams	Diaspididae	Hemiptera
	Leucaspis indica Marlett	Diaspididae	Hemiptera
	Parlatoria calianthina Ber. & Leon.	Diaspididae	Hemiptera
	P. cinerea Hadden	Diaspididae	Hemiptera
	P. pergandii Comst.	Diaspididae	Hemiptera
	Pseudoaulacaspis barberi	Diaspididae	Hemiptera
	Acanthocoris scabrator (Fabr.)	Coreidae	Hemiptera
	Coptosoma nazirae At.	Plataspdidae	Hemiptera
	Lygaeus macilentus (Stoal)	Lygaeidae	Hemiptera
	Spilostethus pandurus (Scop.)	Lygaeidae	Hemiptera
	Antestia cruciata Fabr.	Pentatomidae	Hemiptera
	Bagrada cruciferarum Kirk	Pentatomidae	Hemiptera
	Chrysocoris patricius Fabr.	Pentatomidae	Hemiptera
	Dolycoris indicus St.	Pentatomidae	Hemiptera
	Halymorpha picus	Pentatomidae	Hemiptera
	Halys dentatus (Fb.)	Pentatomidae	Hemiptera
	Jurtina indica	Pentatomidae	Hemiptera
	Nezara viridula (Linn.)	Pentatomidae	Hemiptera
	Dysdercus cingulatus Fabr.	Pyrrhocoridae	Hemiptera
Leaf thrips	*Aeolothrips collaris* Pr.	Aeolothripidae	Thysanoptera
Leaf thrips	*Rhipiphorothrips cruentatus* Hood	Thripidae	Thysanoptera
Thrips	*Scirtothrips dorsalis* Hood.	Thripidae	Thysanoptera
	Thrips hawaiiensis Morgan	Thripidae	Thysanoptera
	Thlibothrips inquilinus	Phlaeothripidae	Thysanoptera

Inflorescence thrips	*Haplothrips ganglbaueri* Schm.	Phlaeothripidae	Thysanoptera
	H. ceylonicus Schm.	Phlaeothripidae	Thysanoptera
	Xylaplothrips pictipes (Ramakrishna)	Phlaeothripidae	Thysanoptera
	Neoheegeria mangiferae Pr.	Phlaeothripidae	Thysanoptera
Inflorescence caterpillar	*Anatrachyntis simplex* Wlsm.	Cosmopterygidae	Lepidoptera
	Anarsia melanoplecta Meyr.	Gelechiidae	Lepidoptera
	Stathmopoda theoris Meyrick	Heliodinidae	Lepidoptera
Leaf miner	*Acrocerocops syngramma* M.	Gracillariidae	Lepidoptera
	A. zygonoma	Gracillariidae	Lepidoptera
Bark borer	*Indarbela tetraonis* M.	Metarbelidae	Lepidoptera
	I. quadrinotata Wlk.	Metarbelidae	Lepidoptera
	Natada velutina Koll.	Limacodiidae	Lepidoptera
Castor slug	*Latoia lepida* C.	Limacodiidae	Lepidoptera
Leaf roller	*Agyroploce aprobola* Meyr.	Eucosmidae	Lepidoptera
	A. erotias Meyr.	Eucosmidae	Lepidoptera
	Spilonota rhothia Meyr.	Eucosmidae	Lepidoptera
	Chloroclystis sp.	Pyralidae	Lepidoptera
	Conogethes punctiferalis (Guen.)	Pyralidae	Lepidoptera
	Ctenomereistis ebriola Meyr.	Pyralidae	Lepidoptera
Fruit borer	*Deanolis albizonalis* (Hampson)	Pyralidae	Lepidoptera
	Herculia sp.	Pyralidae	Lepidoptera
Fruit borer	*Hyalospila leuconeurella* Rag.	Pyralidae	Lepidoptera
	Lamida moncusalis (Wlk.)	Pyralidae	Lepidoptera
	Orthaga euadrusalis Wlk.	Pyralidae	Lepidoptera
	O. exvinacea Hampson	Pyralidae	Lepidoptera
	Phycita umbratelis H.	Pyralidae	Lepidoptera
	Spectrotropha sordidalis Hmpsn.	Pyralidae	Lepidoptera
	Cricula trifenestrata H.	Saturniidae	Lepidoptera
	Symphaedra (=Euthalia) nais (F.)	Nymphalidae	Lepidoptera
Inflorescence caterpillar	*Rapala manea* Hewitson	Lycaenidae	Lepidoptera
	R. melampus Cr.	Lycaenidae	Lepidoptera
	Thalassodes quadraria Guen.	Geometridae	Lepidoptera
	T. veraria Guen.	Geometridae	Lepidoptera
	Achaea janata (Linn.)	Noctuidae	Lepidoptera
	Chelaria spathota Meyr.	Noctuidae	Lepidoptera
Shoot webber	*Chlumetia transversa* Wlk.	Noctuidae	Lepidoptera
	Eublemma angulifera Moore	Noctuidae	Lepidoptera
	E. versicolor Wlk.	Noctuidae	Lepidoptera
	E. silicula Swinh.	Noctuidae	Lepidoptera
	Helicoverpa armigera Hb.	Noctuidae	Lepidoptera
	Orthaga euadrusalis Wlk.	Noctuidae	Lepidoptera
	O. exvinacea H.	Noctuidae	Lepidoptera
Fruit sucking moth	*Othreis divitosa* Wlk.	Noctuidae	Lepidoptera
Fruit sucking moth	*O. fullonica* Linn.	Noctuidae	Lepidoptera
Fruit sucking moth	*P. homaena*	Noctuidae	Lepidoptera
Fruit sucking moth	*O. materna* L.	Noctuidae	Lepidoptera

Leaf feeder	*Penicillaria* (= *Bombotelia*) *jocosatrix* (G.)	Noctuidae	Lepidoptera
	Amsacta lactinea (Cramer)	Arctiidae	Lepidoptera
Hairy caterpillar	*Euproctis flava* Fabr.	Lymantriidae	Lepidoptera
	E. fraterna M.	Lymantriidae	Lepidoptera
	E. lunata Wlk.	Lymantriidae	Lepidoptera
	Lymantria ampla	Lymantriidae	Lepidoptera
	L. mathura Moore	Lymantriidae	Lepidoptera
	L. marginata	Lymantriidae	Lepidoptera
Hairy caterpillar	*Olene mendosa* (Hb.)	Lymantriidae	Lepidoptera
Hairy caterpillar	*Porthesia scientillans* Wlk.	Lymantriidae	Lepidoptera
Leaf gall	*Alassomyia tenuispatha* Kief.	Cecidomyiidae	Diptera
	Amradiplosis allahabadensis Grover	Cecidomyiidae	Diptera
Gall midge	*A. amraemyia* (Rao)	Cecidomyiidae	Diptera
	A. brunneigallicola (Rao)	Cecidomyiidae	Diptera
	A. echinogalliperda Mani	Cecidomyiidae	Diptera
	A. keshopurensis (Rao)	Cecidomyiidae	Diptera
	A. viridigallicola (Rao)	Cecidomyiidae	Diptera
	Asynapta mangiferae Felt	Cecidomyiidae	Diptera
Mango blossom midge	*Dasineura amaramanjarae* Grover	Cecidomyiidae	Diptera
Inflorescence midge	*Erosomyia indica* Grover & Prasad	Cecidomyiidae	Diptera
Gall midge	*Indodiplosis mangiferae* Felt.	Cecidomyiidae	Diptera
	I. mangifoliae Gover	Cecidomyiidae	Diptera
	Mangodiplosis mangiferae	Cecidomyiidae	Diptera
	Meunierella mangiferae	Cecidomyiidae	Diptera
Leaf gall midge	*Procontarinia matteiana* Kief. & Coce.	Cecidomyiidae	Diptera
	P. mangiferae Green	Cecidomyiidae	Diptera
	Procystiphora indica Gr. & Pr.	Cecidomyiidae	Diptera
Blossom gall midge	*P. mangiferae* Mani	Cecidomyiidae	Diptera
	Raodiplosis orientalis	Cecidomyiidae	Diptera
Shoot midge	*Rhabdophaga mangiferae* M.	Cecidomyiidae	Diptera
Fruitfly	*Bactrocera correctus* Bezzi	Tephritidae	Diptera
	B. cucurbitae Coq.	Tephritidae	Diptera
	B. diversus Cog.	Tephritidae	Diptera
	B. dorsalis Hendel	Tephritidae	Diptera
	B. hageni deM	Tephritidae	Diptera
	B. zonatus Saund	Tephritidae	Diptera
	Dorylus orientalis Westw.	Formicidae	Hymenoptera
Red ant	*Oecophylla smaragdina* Fb.	Formicidae	Hymenoptera
	Adoretus lasiopygus Burm.	Rutelidae	Coleoptera
	Anomala varicolor	Rutelidae	Coleoptera
Defoliator	*Holotrichia consanguinea* Bl.	Melolonthidae	Coleoptera
	H. insularis Brenske	Melolonthidae	Coleoptera
Mango jewel beetle	*Belinota prasina* Th.	Buprestidae	Coleoptera
Root borer	*Acanthophorus serraticornis*	Cerambycidae	Coleoptera
	Batocera numerator Newm.	Cerambycidae	Coleoptera

	B. rubus Linn.	Cerambycidae	Coleoptera
Mango stem borer	*B. rufomaculata* DeG	Cerambycidae	Coleoptera
	Plocaederus ferrugineus (Linn.)	Cerambycidae	Coleoptera
	Sthenias grisator Fabr.	Cerambycidae	Coleoptera
	Stromatium barbatum (F.)	Cerambycidae	Coleoptera
	Scelodonta strigicollis M.	Eumolpidae	Coleoptera
	Corticarina gibbosa Herbst.	Lathriidae	Coleoptera
	Lyctus africanus Linn.	Lyctidae	Coleoptera
	Aetheomorpha suturata Jac.	Galeuricidae	Coleoptera
	Chaetocnema cognatata Baly.	Galeuricidae	Coleoptera
	C. concinnipennis Baly.	Galeuricidae	Coleoptera
	Clitea picta Baly.	Galeuricidae	Coleoptera
	Costalimatia ferruginea	Galeuricidae	Coleoptera
	Cryptocephalus sp.	Galeuricidae	Coleoptera
	Diapromorpha melanopus	Galeuricidae	Coleoptera
	D. turcica Fabr.	Galeuricidae	Coleoptera
	Gynandrophthalma sp.	Galeuricidae	Coleoptera
	Haltica coerulea Oliver	Galeuricidae	Coleoptera
	Luperomorpha weisei Jacob	Galeuricidae	Coleoptera
	Monolepta signata Ol.	Galeuricidae	Coleoptera
	Nodostoma dimidiatipes Jac.	Galeuricidae	Coleoptera
	Pagria sp.	Galeuricidae	Coleoptera
	Rhytidodera bowringi Gahan	Galeuricidae	Coleoptera
	R. simulans White	Galeuricidae	Coleoptera
Red pumpkin beetle	*Raphidopalpa foveicollis* Lucas	Galeuricidae	Coleoptera
Flea beetle	*Scelodonta strigicollis* (Mot.)	Galeuricidae	Coleoptera
	Cryptocephalus insubidus S.	Cryptocephalidae	Coleoptera
	C. suillus S.	Cryptocephalidae	Coleoptera
	Verania cardoni W.	Coccinellidae	Coleoptera
	Heterobostrychus aequalis Waterh.	Bostrychidae	Coleoptera
	Parabostrychus elongatus Linn.	Bostrychidae	Coleoptera
	Carpophilus dimidiatus	Nitidulidae	Coleoptera
	Xyleborus affinis Eichh.	Scolytidae	Coleoptera
	X. kraatzi Eichh.	Scolytidae	Coleoptera
	X. semigranosus B.	Scolytidae	Coleoptera
Shoot weevil	*Alcidodes tranatus* Faust	Curculionidae	Coleoptera
	Amblyrrhinus poricollis Boh.	Curculionidae	Coleoptera
Leaf twister	*Apoderus tranquebaricus* F.	Curculionidae	Coleoptera
	Camptorrhinus mangiferae	Curculionidae	Coleoptera
Leaf tip cutter	*Deporaus marginatus* P.	Curculionidae	Coleoptera
Twig boring weevil	*Ectatorhinus adamsi* Pasc.	Curculionidae	Coleoptera
	Myllocerus lactivirens Mshll.	Curculionidae	Coleoptera
Leaf weevil	*M. maculosus* Desbr.	Curculionidae	Coleoptera
	M. sabulossus Mshll.	Curculionidae	Coleoptera
	M. undecimpustulatus Desb.	Curculionidae	Coleoptera
	Peltotrachelus cognatus Mshll.	Curculionidae	Coleoptera
	Platymycterus sjostedti Mshll.	Curculionidae	Coleoptera

Leaf miner or leaf flea weevil	*Rhynchaenus mangiferae* Mshll.	Curculionidae	Coleoptera
Nut weevil	*Sternochetus gravis* (Fabr.)	Curculionidae	Coleoptera
Mango nut weevil or stone weevil	*Sternochetus mangiferae* (Fb.)	Curculionidae	Coleoptera
	***Musa* sp. (BANANA)**		
Desert locust	*Schistocerca gregaria* Forsk.	Acrididae	Orthoptera
White ant	*Glyptotermes dilatatus*	Kalotermitidae	Isoptera
Spittle insect	*Phymatostetha deschampsi* L.	Cercopidae	Hemiptera
Banana aphid	*Pentalonia nigronervosa* Cog.	Aphididae	Hemiptera
Whitefly	*Aleurocanthus musae* D. & J.	Aleyrodidae	Hemiptera
	Aleurolobus musae Corbett	Aleyrodidae	Hemiptera
Spiralling whitefly	*Aleurodicus dispersus* Russell	Aleyrodidae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
	Lecanium discrepans Gr.	Coccidae	Hemiptera
	L. signiferum Gr.	Coccidae	Hemiptera
	Aspidiotus cyanophylli Sign.	Diaspididae	Hemiptera
	A. cydoniae Ckll.	Diaspididae	Hemiptera
	A. destructor Sign.	Diaspididae	Hemiptera
	A. transparens Gr.	Diaspididae	Hemiptera
	Aonidiella aurantii (Mask.)	Diaspididae	Hemiptera
	A. orientalis (Newst.)	Diaspididae	Hemiptera
Mirid bug	*Prodromus subviridis* D.	Miridae	Hemiptera
Banana lace wing bug	*Stephanitis typica* Dist.	Tingidae	Hemiptera
	Stibaropus tabulatus S.	Pentatomidae	Hemiptera
Fruit peal thrips	*Astrothrips parvilimbus* Stan. & Mitri	Thripidae	Thysanoptera
Fruit rust thrips	*Chaetanaphothrips signipennis* (Bagn.)	Thripidae	Thysanoptera
Leaf thrips	*Helionothrips kadaliphilus* R&M	Thripidae	Thysanoptera
	Panchaetothrips indicus Bagn.	Thripidae	Thysanoptera
	Scolothrips asura R & M.	Thripidae	Thysanoptera
Flower thrips	*Thrips hawaiiensis* (Morgan)	Thripidae	Thysanoptera
Bagworm	*Kophene cuprea* M.	Psychidae	Lepidoptera
	Latoia lepida C.	Limacodiidae	Lepidoptera
Hairy caterpillar	*Argina syringa* Cram.	Hypsidae	Lepidoptera
Wooly bear	*Pericallia ricini* Fb.	Arctiidae	Lepidoptera
	Spilarctia obliqua (Walk.)	Arctiidae	Lepidoptera
Hairy caterpillar	*Trabala vishnou* L.	Lasiocampidae	Lepidoptera
	Spodoptera litura (F.)	Noctuidae	Lepidoptera
Hairy caterpillar	*Euproctis fraterna* Moore	Lymantriidae	Lepidoptera
Fruitfly	*Bactrocera dorsalis* Hendel	Tephritidae	Diptera
Leaf beetle	*Nodostoma subcostatum* J.	Eumolpidae	Coleoptera
Rhizome borer	*Cosmopolitus sordidus* G.	Curculionidae	Coleoptera
Pseudostem borer	*Odoiporus longicollis* (Oliv.)	Curculionidae	Coleoptera

Passiflora edulis (PASSION FRUIT)

Green bug	*Lygus viridanus* M.	Miridae	Hemiptera

Phyllanthus acidus (STAR GOOSEBERRY)

Whitefly	*Trialeurodes ricini* (Misra)	Aleyrodidae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
	Scutellera nobilis F.	Scutelleridae	Hemiptera

Prunus amygdalus (ALMOND)

Peach leaf curl aphid	*Brachycaudus helichrysi* kalt	Aphididae	Hemiptera
Aphid	*Pterochloroides persicae* (Cholod)	Aphididae	Hemiptera
	Eulecanium corylii L.	Coccidae	Hemiptera
White scale	*Pseudaulacaspis pentagona* T.	Diaspididae	Hemiptera
Tent caterpillar	*Malacosma indica* Wlk.	Lasiocampidae	Lepidoptera
Stem borer	*Sphenoptera lafertei* Thomson	Buprestidae	Coleoptera
	Mimastra cyanura Hope	Chrysomelidae	Coleoptera

Prunus armeniaca (APRICOT)

Peach leaf curl aphis	*Brachycaudus helichrysi* Kalt.	Aphididae	Coeloptera
Scale insect	*Chionaspis furfura* (Fitch)	Coccidae	Coleoptera
	Eulecanium corylii L.	Coccidae	Coleoptera
Bud caterpillar	*Eucosma oscellana* Schiff.	Eucosmidae	Lepidoptera
	Cacoecia sarcostega Meyr.	Tortricidae	Lepidoptera
Tent caterpillar	*Malacosoma indica* Wlk.	Lasiocampidae	Lepidoptera
Fruitfly	*Bactrocera dorsalis* Hendel	Tephritidae	Diptera
	Lucanus lunifer Hopl.	Lucanidae	Coleoptera
	Macronota 4-lineata Hope	Cetoniidae	Coleoptera
	Torynorrhina opalina Hope	Cetoniidae	Coleoptera
	Brahmina coriacea Hope	Melolonthidae	Coleoptera
	B. crinicollis Burn.	Melolonthidae	Coleoptera
	Lachnosterna longipennis Bl.	Melolonthidae	Coleoptera
	Melolontha furcicauda Ancy.	Melolonthidae	Coleoptera
	Anomala dimidiata Hope	Rutelidae	Coleoptera
	A. duvaceli Bl.	Rutelidae	Coleoptera
	A. flavipes Arrow	Rutelidae	Coleoptera
	A. lineatipennis Bl.	Rutelidae	Coleoptera
	A. polita Bl.	Rutelidae	Coleoptera
	A. rufiventris Redt.	Rutelidae	Coleoptera
	Hilyotrogus holosericeus Redt.	Rutelidae	Coleoptera
	Mimela fulgidividiata Bl.	Rutelidae	Coleoptera
Stem borer	*Sphenoptera lqfertei* Thomson	Buprestidae	Coleoptera
Apple borer	*Aeolesthes holosericea* Fb.	Cerambycidae	Coleoptera
	Lophosternus hugelii Fedt.	Cerambycidae	Coleoptera
Leaf beetle	*Mimastra cyanura* Hope	Chrysomelidae	Coleoptera

Prunus avium (CHERRY)

Cherry aphis	*Myzus cerasi* Fabn.	Aphididae	Hemiptera
	Eulecanium corylii L.	Coccidae	Hemiptera
White scale	*Pseudaulacaspis pentagona* T.	Diaspididae	Hemiptera
	Cacoecia sarcostega Meyr.	Tortricidae	Lepidoptera
Tent caterpillar	*Malacosoma indica* Wlk.	Lasiocampidae	Lepidoptera
	Achelura bifasciata Hope	Zygaenidae	Lepidoptera
Fruitfly	*Bactrocera dorsalis* Hendel	Tephritidae	Diptera
Blossom beetle	*Protaetia impavida* J.	Cetoniidae	Coleoptera
	Melolontha furcicauda Ancy.	Melolonthidae	Coleoptera
	Adoretus bimarginatus Ohow.	Rutelidae	Coleoptera
Stem borer	*Sphenoptera lafertei* Thomson	Buprestidae	Coleoptera
	Mimastra cyanura Hope	Chrysomelidae	Coleoptera
	Pachnephorus impressus Rosenb.	Eumolpidae	Coleoptera
Stem borer	*Aeolesthes holosericea* Fb.	Cerambycidae	Coleoptera
	A. sarta Solsky	Cerambycidae	Coleoptera
Apple root borer	*Dorysthenus hugelii* Redt.	Cerambycidae	Coleoptera

Prunus persica (PEACH)

Pomegranate whitefly	*Siphoninus phillyreae* Haliday	Aleyrodidae	Hemiptera
Peach leaf curl aphis	*Brachycaudus helichrysi* Kalt.	Aphididae	Hemiptera
Cherry aphis	*Myzus cerasi* Fabr.	Aphididae	Hemiptera
Peach stem aphid	*Pterochloroides persicae* (Cholod)	Aphididae	Hemiptera
	Eulecanium corylii L.	Coccidae	Hemiptera
	Lecanium capreae Linn.	Coccidae	Hemiptera
	Aonidiella aurantii (Mask.)	Diaspididae	Hemiptera
	A. cydoniae C.	Diaspididae	Hemiptera
	A. orientalis (Newst.)	Diaspididae	Hemiptera
	A. transparens Gr.	Diaspididae	Hemiptera
	Hemiberlesia lataniae (Sign.)	Diaspididae	Hemiptera
	H. rapex Comst.	Diaspididae	Hemiptera
	Howardia biclavis Comst.	Diaspididae	Hemiptera
	Parlatoria oleae Colv.	Diaspididae	Hemiptera
White scale	*Pseudaulacaspis pentagona* T.	Diaspididae	Hemiptera
San Jose scale	*Quadraspidiotus perniciosus* C.	Diaspididae	Hemiptera
Lygaeid bug	*Spilostethus pandurus* (Scop.)	Lygaeidae	Hemiptera
Stem borer	*Sahyadrussus malabarcius* M.	Hepialidae	Lepidoptera
	Cacoecia sarcostega Meyr.	Tortricidae	Lepidoptera
	Achelura bifasciata Hope	Zygaenidae	Lepidoptera
Tent caterpillar	*Malacosoma indica* Wlk.	Lasiocampidae	Lepidoptera
	Conogethes punctiferalis (Guen.)	Pyralidae	Lepidoptera
Fruit sucking moth	*Calpe ophideroides* Guen.	Noctuidae	Lepidoptera
Hairy caterpillar	*Lymantria obfuscata* Walker	Lymantriidae	Lepidoptera
Tussock caterpillar	*Olene mendosa* Hb.	Lymantriidae	Lepidoptera
Fruitfly	*Bactrocera correctus* Bezzi	Tephritidae	Diptera
	B. cucurbitae Coq.	Tephritidae	Diptera

	B. dorsalis Hendel	Tephritidae	Diptera
	B. duplicatus Bezzi	Tephritidae	Diptera
	B. maculipennis D.	Tephritidae	Diptera
	B. zonatus Saunders	Tephritidae	Diptera
	Lucanus lunifer Hope	Lucanidae	Coleoptera
	Clinteria spilota Hope	Cetoniidae	Coleoptera
	Macronota 4-lineata Hope	Cetoniidae	Coleoptera
	Protaetia neglecta Hope	Cetoniidae	Coleoptera
	Xylotrupes gideon Linn.	Dynastidae	Coleoptera
	Brahmina coriacea Hope	Melolontidae	Coleoptera
	Lachnosterna longipennis Bl.	Melolontidae	Coleoptera
Laef beetle	*Serica pruinosa* Burn.	Melolontidae	Coleoptera
	Anomala flavipes Arrow	Rutelidae	Coleoptera
	A. lineatipennis Bl.	Rutelidae	Coleoptera
	A. rufiventris Redt.	Rutelidae	Coleoptera
	Hilyotrogus holosericeous Redt.	Rutelidae	Coleoptera
	Popillia complanata Newm.	Rutelidae	Coleoptera
	Cantharcius molossus Linn.	Copridae	Coleoptera
Flat-headed borer	*Sphenoptera dadkhani* Obenberger	Buprestidae	Coleoptera
Stem borer	*S. lafertei* Thomson	Buprestidae	Coleoptera
Apple stem borer	*Aeolesthes holosericea* Fb.	Cerambycidae	Coleoptera
Stem borer	*Apriona cinerea* Chever	Cerambycidae	Coleoptera
Apple root borer	*Dorysthenus hugelii* Redt.	Cerambycidae	Coleoptera
	Lophosternus hugelii Redt.	Cerambycidae	Coleoptera
	Cerogria nepalensis Hope	Chrysomelidae	Coleoptera
	Minastra cyanura Hope	Chrysomelidae	Coleoptera
	M. sorali Baly.	Chrysomelidae	Coleoptera

Psidium guajava (GUAVA)

Cowbug	*Tricentrus bicolor* Dist.	Membracidae	Hemiptera
Cotton aphid	*Aphis gossypii* Glov.	Aphididae	Hemiptera
	Aleurocanthus rugosa Singh	Aleyrodidae	Hemiptera
Spiralling whitefly	*Aleurodicus dispersus* Russell	Aleyrodidae	Hemiptera
	Aleurolobus psidii Jesudasan and David	Aleyrodidae	Hemiptera
	Aleuroclava (= Aleurotuberculatus) psidii	Aleyrodidae	Hemiptera
	Dialeurpora decempuncta Q. and B.	Aleyrodidae	Hemiptera
	Pealius misrae Singh	Aleyrodidae	Hemiptera
	Drosicha stebbingi (Gr.)	Margarodidae	Hemiptera
	Hemaispidoproctus cinereus Gr.	Margarodidae	Hemiptera
	Walkeriana polei Gr.	Margarodidae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
Mealy bug	*Maconellicoccus hirsutus* (Green)	Pseudococcidae	Hemiptera
	Ceroplastodes cajani (Mask.)	Coccidae	Hemiptera
	Ceroplastes floridensis Comst.	Coccidae	Hemiptera
	Coccus viridis (Gr.)	Coccidae	Hemiptera

	Chloropulvinaria psidii Gr.	Coccidae	Hemiptera
Waxscale	*Drepanococcus chiton* (Gren)	Coccidae	Hemiptera
	Parasaissestia nigra (Nietn.)	Coccidae	Hemiptera
	Saissetia hemisphaerica (Targ.)	Coccidae	Hemiptera
	S. oleae Ber.	Coccidae	Hemiptera
	Aonidiella aurantii (Mask.)	Diaspididae	Hemiptera
	A. destructor Sign.	Diaspididae	Hemiptera
	A. orientalis (Newst)	Diaspididae	Hemiptera
	A. rossi Mask.	Diaspididae	Hemiptera
	A. transparens Gr.	Diaspididae	Hemiptera
	A trilobitiformis Gr.	Diaspididae	Hemiptera
	Mytilaspis pallida Gr.	Diaspididae	Hemiptera
Tea mosquito bug	*Helopeltis antonii* S.	Miridae	Hemiptera
	Erthesina fulle Thunb.	Pentatomidae	Hemiptera
Giant red bug	*Lohita grandis* Gray	Pyrrhocoridae	Hemiptera
	Scirtothrips dorsalis Hood	Thripidae	Thysanoptera
Bark borer	*Indarbela tetraonis* Moore	Metarbelidae	Lepidoptera
	L quadrinotata Wlk.	Metarbelidae	Lepidoptera
	Altha lacteola Swinhoe	Limacodiidae	Lepidoptera
Borer	*Microcolona leucosticta* Meyr.	Eucosmidae	Lepidoptera
	M. technographa	Eucosmidae	Lepidoptera
	Spilonota rhothia Meyr.	Eucosmidae	Lepidoptera
	Conogethes punctiferalis (Guen.)	Pyralidae	Lepidoptera
	Metanastria hyrtaca C.	Lasiocampidae	Lepidoptera
	M. recta Wlk.	Lasiocampidae	Lepidoptera
	Taragama siva Lefroy	Lasiocampidae	Lepidoptera
Fruit borer	*Rapala varuna* Horsfield	Lycaenidae	Lepidoptera
Pomegranate butterfly	*Deudorix isocrates* F.	Lycaenidae	Lepidoptera
Castor semilooper	*Achaea janata* Linn.	Noctuidae	Lepidoptera
Fruit sucking moth	*Othreis fullonica* (L.)	Noctuidae	Lepidoptera
Fruit fly	*Bactrocera correcta* Bezzi	Tephrididae	Diptera
Fruitfly	*B. cucurbitae* Coq.	Tephrididae	Diptera
	B. diversus Coq.	Tephrididae	Diptera
	B. dorsalis Hendel	Tephrididae	Diptera
	B. incisus W.	Tephrididae	Diptera
	B. zonatus Saund.	Tephrididae	Diptera
Leaf defoliator	*Holotrichia consanguinea* Bl.	Melolonthidae	Coleoptera
	H. insularis Brenske	Melolonthidae	Coleoptera
Stem borer	*Aeolesthes holosericea* Fb.	Cerambycidae	Coleoptera
Trunk borer	*Aristobia testudo* V.	Cerambycidae	Coleoptera
Leaf weevil	*Myllocerus discolor* var. *variegatus* B	Curculionidae	Coleoptera

Punica granatum (POMEGRANATE)

Spiralling whitefly	*Aleurodicus dispersus* Russell	Aleyrodidae	Hemiptera
Pomegranate whitefly	*Siphoninus phillyreae* Haliday	Aleyrodidae	Hemiptera
Greenhouse whitefly	*Trialeurodes vaporariorum* (Westwood)	Aleyrodidae	Hemiptera

Aphid	*Aphis punicae* Passerini	Aphididae	Hemiptera
	Hemiaspidoproctus cinereus (Gr.)	Margarodidae	Hemiptera
	Icerya formicarum Newstead	Margarodidae	Hemiptera
	Walkeriana senex (Gr.)	Margarodidae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
Mealy bug	*Maconellicoccus hirsutus* (Green)	Pseudococcidae	Hemiptera
Scale insect	*Parasaissetia nigra* (Nietner)	Coccidae	Hemiptera
	Planococcus citri (Risso)	Coccidae	Hemiptera
	P. lilacinus (Ckll.)	Coccidae	Hemiptera
	Aspidiotus rossi Mask.	Diaspididae	Hemiptera
	Duplaspidiotus tesseratus Dech.	Diaspididae	Hemiptera
	Lepidosaphes hawaiiensis Mask.	Diaspididae	Hemiptera
	Pinnapis theae (Mask.)	Diaspididae	Hemiptera
Fruit bug	*Halyomorpha piceus* D.	Pentatomidae	Hemiptera
	Jurtina indica D.	Pentatomidae	Hemiptera
	Plautia crossota (Dallas)	Pentatomidae	Hemiptera
	Flata ferrugata (Fb.)	Flatidae	Hemiptera
Leaf thrips	*Retithrips syriacus* (Mayet)	Thripidae	Thysanoptera
	Rhipiphorothrips cruentatus Hood	Thripidae	Thysanoptera
Coffee red borer	*Zeuzera coffeae* Nietn.	Zeuzeridae	Lepidoptera
Bagworm	*Acanthopsyche cana* Hampson	Psychidae	Lepidoptera
Bagworm	*Eumeta crameri* (Westw.)	Psychidae	Lepidoptera
	Pteroma sp.	Psychidae	Lepidoptera
Bark borer	*Indarbela quadrinotata* Walker	Metarbelidae	Lepidoptera
	I. tetraonis Moore	Metarbelidae	Lepidoptera
	Latoia lepida C.	Limacodiidae	Lepidoptera
	Conogethes punctiferalis (Guen.)	Pyralidae	Lepidoptera
	Euzophera punicella	Pyralidae	Lepidoptera
Pomegranate butterfly	*Deudorix (= Virachola) isocrates* F.	Lycaenidae	Lepidoptera
Leaf eating caterpillar	*Freyeria putli* (Kollar)	Lycaenidae	Lepidoptera
Hairy caterpillar	*Trabala vishnou* L.	Lasiocampidae	Lepidoptera
	Achaea janata Linn.	Noctuidae	Lepidoptera
Fruit borer	*Helicoverpa armigera* (Hb.)	Noctuidae	Lepidoptera
Fruit sucking moth	*Othreis fullonica* (Linn.)	Noctuidae	Lepidoptera
	O. homaena	Noctuidae	Lepidoptera
	O. materna (Linn.)	Noctuidae	Lepidoptera
Tussock caterpillar	*Euproctis fraterna* M.	Lymantriidae	Lepidoptera
	Porthesia scintillans W.	Lymantriidae	Lepidoptera
Hairy caterpillar	*Creatonotus gangis* (Linn.)	Arctiidae	Lepidoptera
Fruitfly	*Bactrocera zonatus* Saund	Tephritidae	Diptera
	Anomala dimidiata (Hope)	Rutelidae	Coleoptera
	A. dorsalis (Fabricius)	Rutelidae	Coleoptera
	A. ruficapilla (Burmeister)	Rutelidae	Coleoptera
Mango stem borer	*Coelosterna scabrator* (Fb.)	Cerambycidae	Coleoptera
	Olenecamptus bilobus F.	Cerambycidae	Coleoptera
	Lasioderma serricorne (Fb.)	Anobiidae	Coleoptera

	Mimastra cyanura Hope	Chrysomelidae	Coleoptera
	Hoplasoma sexmaculata Hope	Chrysomelidae	Coleoptera
	Myllocerus maculosus Desbr.	Curculionidae	Coleoptera
	M. tenuicornis (Faust)	Curculionidae	Coleoptera
	Chiloloba acuta (Wiedemann)	Cetoniidae	Coleoptera
	Oxycetonia versicolor (Fabricius)	Cetonoiidae	Coleoptera
Shot hole borer	*Euvallacea fornicatus* (Eichhoff)	Scolytidae	Coleoptera
	Xyleborus perforans (W.)	Scolytidae	Coleoptera

***Pyrus communis* (PEAR)**

Leafhopper	*Jassus paauperculus* Spangle	Circadellidae	Hemiptera
Apple psylla	S. *Psylla mali*	Psyllidae	Hemiptera
Pomegranate whitefly	*Siphoninus phillyreae* Haliday	Aleyrodidae	Hemiptera
Pear aphis	*Lachnus krishnii* G.	Aphididae	Hemiptera
	Macrosiphum rosae L.	Aphididae	Hemiptera
	'Nippolachnus pyri (Matsumura)	Aphididae	Hemiptera
	Hemiberlesia lataniae (Sign.)	Margarodidae	Hemiptera
	H. rapex Comst.	Margarodidae	Hemiptera
	Eriochiton theae (Gr.)	Coccidae	Hemiptera
	Eulecanium corylii L.	Coccidae	Hempitera
	Lecanium remarkrishnae (Gr.)	Coccidae	Hemiptera
	Saissetia hemisphaerica (Targ.)	Coccidae	Hemiptera
	Aonidiella aurantii (Mask.)	Diaspididae	Hemiptera
	Aspidiotus transparens Gr.	Diaspididae	Hemiptera
	Parlatoria cinerea Hadden	Diaspididae	Hemiptera
	P. oleae Colv.	Diaspididae	Hemiptera
	Parlatoriopsis chinensis (Mariatt)	Diaspididae	Hemiptera
San Jose scale	*Quadraspidiotus perniciosus* (Comst.)	Diaspididae	Hemiptera
Leaf thrips	*Heliothrips haemorrhoidalis* B.	Thripidae	Thysanoptera
Stem borer	*Sahyadrussus malabaricus* M.	Hepialidae	Lepidoptera
Bud caterpillar	*Eucosma ocellana* Schiff.	Eucosmidae	Lepidoptera
	Enarmonia pomonella (L.)	Eucosmidae	Lepidoptera
	Cacoecia sarcostega Meyr.	Tortricidae	Lepidoptera
Pear leaf caterpillar	*Rhopobota raevana* Hb.	Tortricidae	Lepidoptera
Tent caterpillar	*Malacosoma indica* WIk.	Lasiocampidae	Lepidoptera
	Conogethes punctiferalis (Guen.)	Pyralidae	Lepidoptera
	Actias selene Hb.	Saturniidae	Lepidoptera
	Euroctis fraterna M.	Lymantriidae	Lepidoptera
	Vespa orientalis Fb.	Vespidae	Hymenoptera
Fruitfly	*Bactrocera dorsalis* Hendel	Tephritidae	Diptera
	B. zonatus Saund.	Tephritidae	Diptera
	Lucanus lunifer Hope	Lucanidae	Coleoptera
	Macronota 4-lineata Hope	Melolonthidae	Coleoptera
	Brahmina coriacea Hope	Cetoniidae	Coleoptera
	Lachnosterna longipennis Bl.	Melolonthidae	Coleoptera
	Adoretus horticola	Rutelidae	Coleoptera

	A. versutus	Rutelidae	Coleoptera
	Anomala flavipes Arrow	Rutelidae	Coleoptera
	A. rufiventris Redt.	Rutelidae	Coleoptera
	A. lineatipennis Bl.	Rutelidae	Coleoptera
	Hilyotrogus holosericeus Redt.	Rutelidae	Coleoptera
Apple stem borer	*Aeolesthes holosericea* Fb.	Cerambycidae	Coleoptera
Apple root broer	*Dorysthenus hugelii* Redt.	Cerambycidae	Coleoptera
	Lophosternus hugelii Redt.	Cerambycidae	Coleoptera
	Mimastra cyanura Hope	Chrysomelidae	Coleoptera
	Nodostoma pubicolle J.	Eumolpidae	Coleoptera
	Hypera variabilis H.	Curculionidae	Coleoptera
	Myllocerus maculosus Desbr.	Curculionidae	Coleoptera
	M. subfasciatus G.	Curculionidae	Coleoptera
	M. suspiciens M.	Curculionidae	Coleoptera
	M. viridanus F.	Curculionidae	Coleoptera

Pyrus domesticus **(PLUM)**

Peach leaf curl aphis	*Brachycaudus helichrysi* Kalt.	Aphididae	Hemiptera
	Hemiberlesia rapex Comst.	Margarodidae	Hemiptera
	Eulecanium corylii L.	Coccidae	Hemiptera
White scale	*Pseudaulacaspis pentagons* T.	Diaspididae	Hemiptera
Stem borer	*Sahyadrussus malabaricus* M.	Hepialidae	Lepidoptera
	Achelura bifasciata Hope	Zygaenidae	Lepidoptera
	Mimela princeps H.	Limacodiidae	Lepidoptera
	Eucosoma ocellana Schiff	Eucosomidae	Lepidoptera
	Cacoecia sarcostega Meyr.	Tortricidae	Lepidoptera
Fruitfly	*Bactrocera dorsalis* Hendel	Tephritidae	Diptera
	Lucanus lunifer Hope	Lucanidae	Coleoptera
	Macronota 4-lineata Hope	Cetoniidae	Coleoptera
	Xylotrupes gideon Linn.	Dynastidae	Coleoptera
	Brahmina coriacea Hope	Melolonthidae	Coleoptera
	Lachnosterna longipennis Bl.	Melolonthidae	Coleoptera
	Anomala flavipes Arrow	Rutelidae	Coleoptera
	A. lineatipennis Bl.	Coleoptera	Coleoptera
	A. rufiventris Redt.	Rutelidae	Coleoptera
	Hilyotrogus holosericeus Redt.	Rutelidae	Coleoptera
	Popillia cyanea Hope	Rutelidae	Coleoptera
Stemborer	*Sphenoptera lqfertei* Thomson	Buprestidae	Coleoptera
Apple stem borer	*Aeolesthes holosericea* Fb.	Cerambycidae	Coleoptera
Apple root borer	*Dorsythenus hungelii* Redt.	Cerambycidae	Coleoptera
	Lophosternus hungellii Redt.	Cerambycidae	Coleoptera
	Cerogria nepalensis Hope	Chrysomelidae	Coleoptera
	Mimastra cyanea Hope	Chrysomelidae	Coleoptera
	M. Cyanura Hope	Chrysomelidae	Coleoptera
	Haltica caerulescens Baly.	Alticidae	Coleoptera
	Nodostoma pubicolle J.	Eumolpidae	Coleoptera
Leaf weevil	*Myllocerus subfacinatus* G.	Curculionidae	Coleoptera
	M. suspiciens M.		

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Pyrus malus (APPLE)

Apple psylla	*Psylla mali* S.	Psyllidae	Hemiptera
	Aphis gossypii G.	Aphididae	Hemiptera
Apple woolly aphis	*Eriosoma lanigera* (Hausmn.)	Aphididae	Hemiptera
Pear aphid	*Lachnus krishnii* G.	Aphididae	Hemiptera
	Hemiberlesia lataniae (Sign.)	Margarodidae	Hemiptera
	H. rapex Comst.	Margarodidae	Hemiptera
Cottony cushion scale	*Icerya purchasi* M.	Margarodidae	Hemiptera
	Eulecanium corylii L.	Coccidae	Hemiptera
	Aspidiotus cydoniae C.	Diaspididae	Coleoptera
	Chrysomphalus dictyospermi M.	Diaspididae	Coleoptera
	Duplaspidiotus tesseratus Dech.	Diaspididae	Coleoptera
	Howardia biclavis Comst.	Diaspididae	Coleoptera
White scale	*Pseudaulacaspis pentagona* T.	Diaspididae	Coleoptera
San Jose scale	*Quadraspidiotus perniciosus* (Comst.)	Diaspididae	Coleoptera
	Helopeltis antonii S.	Miridae	Coleoptera
	Lygus viridanus M.	Miridae	Coleoptera
Flower thrips	*Thrips flavus* Schm.	Thripidae	Thysanoptera
	Thrips hawaiiensis (Morgan)	Thripidae	Thysanoptera
Stem borer	*Sahyadrussus malabaricus* M.	Hepialidae	Lepidoptera
Apple fruit borer	*Argyresthia conjugella* Zeller	Yponomeutidae	Lepidoptera
Bud caterpillar	*Eucosma ocellana* Schiff.	Eucosmidae	Lepidoptera
Leaf folder	*Archips pomivora* Meyr.	Tortricidae	Lepidoptera
	Cacoecis sarcostega Meyr.	Tortricidae	Lepidoptera
Pear leaf caterpillar	*Rhopobota raevana* Hb.	Tortricidae	Lepidoptera
Tent caterpillar	*Malacosoma indica* Wlk.	Lasiocampidae	Lepidoptera
	Actias selene Hb.	Saturniidae	Lepidoptera
	Agalope hyalina Kollar	Zygaenidae	Lepidoptera
	Eterusia pulchella Kollar	Zygaenidae	Lepidoptera
	Soritia leptalina Kollar	Zygaenidae	Lepidoptera
	Deudorix isocrates F.	Lycaenidae	Lepidoptera
Cutworm	*Agrotis ipsilon* (Hufn).	Noctuidae	Lepidoptera
Tobacco caterpillar	*Spodoptera litura* (Fb.)	Noctuidae	Lepidoptera
	Thysanoplusia orichalcea F.	Noctuidae	Lepidoptera
Cutworm	*Xestia c-nigrum* (L.)	Noctuidae	Lepidoptera
Hairy caterpillar	*Euproctis fraterna* M.	Lymantriidae	Lepidoptera
	E. sinnata B.	Lymantriidae	Lepidoptera
	Lymantria obfuscata Wlk.	Lymantriidae	Lepidoptera
	Perina nuda F.	Lymantriidae	Lepidoptera
	Porthesia scintillans W.	Lymantriidae	Lepidoptera
Fruitfly	*Bactrocera dorsalis* Hendel	Tephritidae	Diptera
	B. zonatus Saund.	Tephritidae	Diptera
	Lucanus lunifer Hope	Lucanidae	Coleoptera
	Cladognatha giraffa F.	Lucanidae	Coleoptera
	Clinteria spilota Hope	Cetoniidae	Coleoptera

	Macronota 4-lineata Hope	Cetoniidae	Coleoptera
	Protaetia neglecta Hope	Cetoniidae	Coleoptera
	Rhomborrhina glabirhima West.	Cetoniidae	Coleoptera
	Torynorrhina opalina Hope	Cetoniidae	Coleoptera
	Xylotrupes gideon Linn.	Dynastidae	Coleoptera
	Brachmina coriacea Hope	Melolonthidae	Coleoptera
	B. crinicollics Burn.	Melolonthidae	Coleoptera
	Lachnosterna longipennis Bl.	Melolonthidae	Coleoptera
	Melolontha furcicauda Ancy.	Melolonthidae	Coleoptera
	M. indica Hope	Melolonthidae	Coleoptera
	Adoretus bimarginatus Ohow.	Rutelidae	Coleoptera
	A. versutus Harold	Rutelidae	Coleoptera
	Anomala dimidiata Hope	Rutelidae	Coleoptera
	A. flavipes Arrow	Rutelidae	Coleoptera
	A. lineatipennis Bl.	Rutelidae	Coleoptera
	A. polita Bl.	Rutelidae	Coleoptera
	A. rufiventris Redt.	Rutelidae	Coleoptera
	A. rugosa Arrow	Rutelidae	Coleoptera
	Popillia complanata Newm.	Rutelidae	Coleoptera
	P. cyanea Hope	Rutelidae	Coleoptera
	Hilyotrogus holosericeus Redt.	Rutelidae	Coleoptera
	Cantharcius molossus Linn.	Copridae	Coleoptera
Stem borer	*Sphenoptera lafertei* Thomson	Buprestidae	Coleoptera
	Autocrates aenleus Parry	Trictenotomidae	Coleoptera
Apple stem borer	*Aeolesthes holosericea* Fb.	Cerambycidae	Coleoptera
Stem borer	*Apriona cinerea* Cheven	Cerambycidae	Coleoptera
Apple root borer	*Dorysthenus hugelii* Redt.	Cerambycidae	Coleoptera
	Lophosternus hugelii Redt.	Cerambycidae	Coleoptera
	Cerogria nepalensis Hope	Chrysomelidae	Coleoptera
Apple shoot beetle	*Eubrachis indica* Baly.	Chrysomelidae	Coleoptera
	Merista sexmaculata Kollar	Chrysomelidae	Coleoptera
	M. trifasciata Hope	Chrysomelidae	Coleoptera
	Mimastra costatipennis T.	Chrysomelidae	Coleoptera
	M. cyanura Hope	Chrysomelidae	Coleoptera
	Nodostoma pubicolle J.	Eumolpidae	Coleoptera
Fruit weevil	*Dyscerus clathratus* (Pasc.)	Curculionidae	Coleoptera
	D. fletcheri Mshl.	Curculionidae	Coleoptera
	D. malignus Mshl.	Curculionidae	Coleoptera
Ash weevil	*Myllocerus maculosus* Desbr.	Curculionidae	Coleoptera
	M. subfasciatus G.	Curculionidae	Coleoptera
	M. suspiciens M.	Curculionidae	Coleoptera
Shot hole borer	*Scolytus nitidus* Schedl.	Scolytidae	Coleoptera

Syzigium cumini (s. jambolanum) **(JAMUN)**

Psyllid gall	*Megatrioza vitiensis* (Kirkaldy)	Psyllidae	Hemiptera
	Trioza jambolanae C.	Psyllidae	Hemiptera

	Aleurocanthus rugosa Singh	Aleyrodidae	Hemiptera
	Dialeurodes indicus David and Sub.	Aleyrodidae	Hemiptera
	Kanakarajiella vulgaris (Singh)	Aleyrodidae	Hemiptera
	Rhachisphora trilobitoides (Q. and B.)	Aleyrodidae	Hemiptera
	Rusostigma eugeniae (Maskell)	Aleyrodidae	Hemiptera
	Singhiella bicolor (Singh)	Aleyrodidae	Hemiptera
Scale insect	*Chloropulvinaria psidii* Mask.	Coccidae	Hemiptera
	Aonidiella orientalis (Newst.)	Diaspididae	Hemiptera
	Aspidiotus destructor Sign.	Diaspididae	Hemiptera
Giant red bug	*Lohita grandis* Gray	Pyrrhocoridae	Hemiptera
	Leeuwenia ramakrishnae Anan.	Thripidae	Thysanoptera
Leaf thrips	*Mallothrips indicus* R.	Phlaeothripidae	Thysanoptera
	Rhipiphorothrips cruentatus Hood	Thripidae	Thysanoptera
	Teuchothrips eugeniae Sesh. and Anan.	Phlaeothripidae	Thysanoptera
Flower thrips	*Thrips florum* Sch.	Thripidae	Thysanoptera
Leaf miner	*Acrocercops phaeospora* Meyr.	Gracillariiae	Lepidoptera
	A. telestis Meyr.	Gracillariidae	Lepidoptera
Bark borer	*Indarbela tetraonis* M.	Metarbelidae	Lepidoptera
	I. quadrinotata W.	Metarbelidae	Lepidoptera
Leaf roller	*Argyroploce aprobola* Meyr.	Eucosmidae	Lepidoptera
Leaf miner	*A. mormopa* Meyr.	Eucosmidae	Lepidoptera
	Spilonota rhothia Meyr.	Eucosmidae	Lepidoptera
Leaf scraper	*Lepidogma* sp.	Pyralidae	Lepidoptera
Hairy caterpillar	*Metanastria hyrtaca* C.	Lasiocampidae	Lepidoptera
Hairy caterpillar	*Trabala vishnou* L.	Lasiocampidae	Lepidoptera
Fruit borer	*Meridarches reprobata* Meyr.	Carposinidae	Lepidoptera
Plume moth	*Exelastis atomosa* Wlsm.	Pterophoridae	Lepidoptera
Leaf defoliator	*Chrysocraspeda olearia* Guen.	Geometridae	Lepidoptera
Looper caterpillar	*Oenospila flavifusata* Wlk.	Geometridae	Lepidoptera
	Penicillaria jocosatrix G.	Noctuidae	Lepidoptera
Leaf caterpillar	*Carea subtilis* W.	Noctuidae	Lepidoptera
	Orthaga sp.	Noctuidae	Lepidoptera
	Phlegetonia delatrix Guen.	Noctuidae	Lepidoptera
Tussock caterpillar	*Euproctis fraterna* M.	Lymantriidae	Lepidoptera
Fruitfly	*Bactrocera correctus* B.	Tephritidae	Diptera
Leaf beetle	*Holotrichia insularis Brenske*	Melolonthidae	Coleoptera
Leaf twisting weevil	*Apoderus tranquebaricus* F.	Curculionidae	Coleoptera
Fruit weevil	*Balaninus c-album*	Curculionidae	Coleoptera
Ash weevil	*Myllocerus curvicornis* (F.)	Curculionidae	Coleoptera

Tamarindus indica (TAMARIND)

Cuwbug	*Leptocentrus obliquus* W.	Membracidae	Hemiptera
	Otinotus oneratus W.	Membracidae	Hemiptera
	Oxyrhachis tarandus	Membracidae	Hemiptera
	Acaudaleyrodes rachispora (Singh)	Aleyrodidae	Hemiptera

	Aleurolobus niloticus (Pr. and Hosny)	Aleyrodidae	Hemiptera
	Viennotaleyrodes indicus J. and D.	Aleyrodidae	Hemiptera
	Drosichiella tamarindus (Gr.)	Margarodidae	Hemiptera
	Hemiberlesia lataniae (Sign.)	Margarodidae	Hemiptera
	Nippaecoccus vastator (Mask.)	Pseudococidae	Hemiptera
	Planococcus lilacinus (Ckll.)	Pseudococidae	Hemiptera
Fruit scale	*Saissetia oleae* Ber.	Coccidae	Hemiptera
	Aonidiella orientalis (Newst.)	Diaspididae	Hemiptera
	Aspidiotus destructor Sign.	Diaspididae	Hemiptera
	Aspidiotus transparens Gr.	Diaspididae	Hemiptera
	A. tamarindi Gr.	Diaspididae	Hemiptera
Fruit scale	*Cardiococcus castilloae* (Gr.)	Diaspididae	Hemiptera
	Chionaspis acuminata var. *atricolor* G.	Diapididae	Hemiptera
	Pinnaspis temporaria Ferris	Diaspididae	Hemiptera
Lac insect	*Kerria lacca* (Kerr)	Kerridae	Hemiptera
	Haplothrips ceylonicus Schm.	Thripidae	Thysanoptera
	Ramaswamiella subnudula Ky.	Thripidae	Thysanoptera
	Scritothrips dorsalis Hook	Phaeothripidae	Thysanoptera
Bagworm	*Chaliodes vitrea* H.	Psychidae	Lepidoptera
	Pteroma plagiophleps H.	Psychidae	Lepidoptera
	Oecadarchis sp.	Gracillariidae	Lepidoptera
	Thosea aperiens Wlk.	Limacodiidae	Lepidoptera
Fruit borer	*Argyroploce illepida* Bult.	Eucosmidae	Lepidoptera
Flower webber	*Laspeyresia palamedes* M.	Eucosmidae	Lepidoptera
	Aphomia gularis Zell.	Pyralidae	Lepidoptera
	Assaria albicostalis Wlk.	Pyralidae	Lepidoptera
Stored grain larva	*Cadra cautella* (Wlk.)	Pyralidae	Lepidoptera
	Corcyra cephalonica St.	Pyralidae	Lepidoptera
	Conogethes punctiferalis (Guen.)	Pyralidae	Lepidoptera
Fruit borer	*Phycita orthoclina* Meyr.	Pyralidae	Lepidoptera
	Deudorix isocrates F.	Lycaenidae	Lepidoptera
	Thalassodes quadraria Guen.	Geometridae	Lepidoptera
	Stauropus alternus Wlk.	Notodontidae	Lepidoptera
Hairy caterpillar	*Trabala vishnou* F.	Lasiocampidae	Lepidoptera
Flower webber	*Eublemma angulifera* Moore	Noctuidae	Lepidoptera
Leaf defoliator	*Holotrichia insularis* Br.	Melolonthidae	Lepidoptera
Storage pest	*Alphitobius laevigatus* (Fb.)	Tenebrionidae	Lepidoptera
Seed bruchid	*Caryedon gonagra* F.	Bruchidae	Lepidoptera
Seed bruchid	*C. serratus*	Bruchidae	Lepidoptera
Seed beetle	*Araecerus suttiralis* Boh.	Anthribiidae	Lepidoptera
	Calandra linearis Hbst.	Curculionidae	Lepidoptera
	C. oryzae Linn.	Curculionidae	Lepidoptera
Ash weevil	*Myllocerus curvicornis* (F.)	Curculionidae	Lepidoptera

Terminalia catappa (COUNTRY ALMOND)

	Saissetia hemisphaerica (Targ.)	Coccidae	Hemiptera
	Parasaissetia nigra (Nietn.)	Coccidae	Hemiptera
Grapevine thrips	*Rhipiphorothrips cruentatus* Hood	Thripidae	Thysanoptera
	Latoia lepida C.	Limacodiidae	Lepidoptera
	Spatulicraspeda castaneiceps Hmpsn.	Limacodiidae	Lepidoptera
	Metanastria hyrtaca C.	Lasiocampidae	Lepidoptera
	Trabala vishnou L.	Lasiocampidae	Lepidoptera
	Cricula triferestrata H.	Saturniidae	Lepidoptera
	Roeselia fola Swinh.	Arctiidae	Lepidoptera
	Hyblaea puera Cram.	Noctuidae	Lepidoptera
	Selepa celtis Moore	Noctuidae	Lepidoptera
	Olene mendosa Hb.	Lymantriidae	Lepidoptera
	Porthesia scintillans W.	Lymantriidae	Lepidoptera
Leaf twister	*Apoderus tranquebaricus* F.	Curculionidae	Coleoptera
	Myllocerus discolor Fb.	Curculionidae	Coleoptera
	M. viridanus Fb.	Curulionidae	Coleoptera

Vitis vinifera (GRAPEVINE)

White ant	*Odontotermes obesus* R.	Termitidae	Isoptera
	Hemiberlesia lataniae (Sign.)	Margarodidae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
Mealy bug	*Maconellicoccus hirsutus* (Green)	Pseudococcidae	Hemiptera
	Nipaecoccus vastator (Mask.)	Pseudococcidae	Hemiptera
	Coccus longulum (D.)	Coccidae	Hemiptera
	Chloropulvinaria maxima Gr.	Coccidae	Hemiptera
	Parthenolecanium corni (Bouche)	Coccidae	Hemiptera
	Aspidiotus cydoniae C.	Diaspididae	Hemiptera
Grapevine aleyrodid	*Aleurocanthus spiniferus* Q.	Aleyrodidae	Hemiptera
	Helopeltis antonii S.	Miridae	Hemiptera
Thrips	*Florithrips traegardhi* (Trybom)	Thripidae	Thysanoptera
Thrips	*Frankliniella schultzei* Trybom	Thripidae	Thysanoptera
Thrips	*Retithrips syriacus* (Mayet)	Thripidae	Thysanoptera
Thrips	*Rhipiphorothrips cruentatus* Hood	Thripidae	Thysanoptera
Berry scab thrips	*Scirtothrips dorsalis* Hood	Thripidae	Thysanoptera
	Thrips hawaiiensis (Morgan)	Thripidae	Thysanoptera
Leaf miner	*Phyllocnistis toparcha* Meyr.	Gracillariidae	Lepidoptera
Berry borer	*Adoxophyes privatana* (Wlk.)	Tortricidae	Lepidoptera
Leaf roller	*Sylepta lunalis* G.	Pyralidae	Lepidoptera
Berry plume moth	*Oxyptilus regulus* Meyr.	Pterophoridae	Lepidoptera
	Hippotion celerio L.	Sphingidae	Lepidoptera
Fruit-piercing moth	*Achaea janata* Linn.	Noctuidae	Lepidoptera
	Anomis flava F.	Noctuidae	Lepidoptera
	Grammodes stolida Fabr.	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera

	Hulodes caranea Cr.	Noctuidae	Lepidoptera
	Logoptera dotata Fb.	Noctuidae	Lepidoptera
	Othreis homaena	Noctuidae	Lepidoptera
	O. fullonica Linn.	Noctuidae	Lepidoptera
	O. materna Moore	Noctuidae	Lepidoptera
	Paralellia algira Linn.	Noctuidae	Lepidoptera
	Pericyma glaucinans Guen.	Noctuidae	Lepidoptera
	Condica capensis Guen.	Noctuidae	Lepidoptera
	Polydesma umbricola Boisd.	Noctuidae	Lepidoptera
	Remigia archesia Cr.	Noctuidae	Lepidoptera
	R. frugalis F.	Noctuidae	Lepidoptera
	Serrodes inara Cram.	Noctuidae	Lepidoptera
	Sphingomorpha chlorea Cram.	Noctuidae	Lepidoptera
	Spodoptera litura (Fb.)	Noctuidae	Lepidoptera
Berry wasp	*Polistes hebrieus* (Fb.)	Vespidae	Hymenoptera
	Vespa orientalis Linn.	Vespidae	Hymenoptera
	Hypsa ficus Fabr.	Hypsidae	Hymenoptera
Ground beetle	*Gonocephalum depressum* Th.	Tenebrionidae	Coleoptera
Vine borer	*Amphicerus anobioides* (Waterh.)	Bostrycidae	Coleoptera
	Celosterna scabrator Fb.	Cerambycidae	Coleoptera
Stem girdler	*Sthenias grisator* Fb.	Cerambycidae	Coleoptera
	Adoretus bengalensis B.	Rutelidae	Coleoptera
	Adoretus brachyphagus Burm.	Rutelidae	Coleoptera
	A. duvauceli Bl.	Rutelidae	Coleoptera
	A. horticola Arrow	Rutelidae	Coleoptera
	A. lasiopygus B.	Rutelidae	Coleoptera
	A. ovalis	Rutelidae	Coleoptera
	A. versutus Harold	Rutelidae	Coleoptera
	Anomala dimidiata Hope	Rutelidae	Coleoptera
	A. duvauceli (Blanch)	Rutelidae	Coleoptera
	Anomala bengalensis Blanch	Rutelidae	Coleoptera
	A. dorsalis (F.)	Rutelidae	Coleoptera
Whitegrub	*Apogonia* sp. nr. *ruficapilla* Burm.	Melolonthidae	Coleoptera
	Schizonycha ruficollis (F.)	Melolonthidae	Coleoptera
Leaf beetle	*Mimastra cyanea* Hope	Chrysomelidae	Coleoptera
	Oides scutellata Hope	Galeuricidae	Coleoptera
Grapevine flea beetle	*Scelodonta strigicollis* M.	Eumolpidae	Coleoptera

Zizyphus elegans (_Z. jujuba; Z. mauritiana)_ (BER)

Cowbug	*Leptocentrus obliquus* W.	Membracidae	Hemiptera
	Tricentrus bicolor Dist.	Membracidae	Hemiptera
Green leaf hopper	*Empoasca devastans* D.	Cicadellidae	Hemiptera
	Quadraria pakistanika Ahmed	Cicadellidae	Hemiptera
	Aleurolobus niloticus Pr. and Hosny	Aleyrodidae	Hemiptera
Spitle bug	*Machaerota planitiae* Distant	Cercopidae	Hemiptera
Lac insect	*Kerria lacca* (Kerr.)	Kerridae	Hemiptera

	Nipaecoccus vastator (Mask.)	Pseudococcidae	Hemiptera
Mealybug	*Maconellicoccus hirsutus* (Green)	Pseudococcidae	Hemiptera
Ber mealy bug	*Perissopneumon tamarindus* (Green)	Margarodidae	Hemiptera
	Ceroplastodes cajani Mask.	Coccidae	Hemiptera
	Chloropulvinaria maxima Gr.	Coccidae	Hemiptera
Wax scale	*Drepanococcus chiton* (Green)	Coccidae	Hemiptera
	Lecanium discrepans Gr.	Coccidae	Hemiptera
	Pulvinari burkilli Gr.	Coccidae	Hemiptera
	Aonidiella orientalis Newst.	Diaspididae	Hemiptera
	Aspidiotus transparens Gr.	Diaspididae	Hemiptera
	Chionaspis megaloba Gr.	Diaspididae	Hemiptera
Green striped leaf hopper	*Eurybrachys tomentosa* Fab.	Eurybrachidae	Hemiptera
	Urentius ziziphifolius Menon and Hakk	Tingidae	Hemiptera
	Monosteira minutula Montandon.	Tingidae	Hemiptera
	Tessaratoma javanica Thunb.	Pentatomidae	Hemiptera
Thrips	*Dolichothrips indicus* (H.)	Phlaeothripidae	Thysanoptera
Thrips	*Scirtothrips dorsalis* Hood	Thripidae	Thysanoptera
Leaf webber	*Psorosticha (= Tonica) zizyphi*	Depressariidae	Lepidoptera
Bark borer	*Indarbela tetraonis* M.	Metarbelidae	Lepidoptera
	L quadrinotata W.	Metarbelidae	Lepidoptera
	Thosea aperiens Wlk.	Limacodiidae	Lepidoptera
Leaf roller	*Synclera univocalis* Walk.	Pyralidae	Lepidoptera
Fruit borer	*Meridarchis scyrodes* Meyr.	Carposinidae	Lepidoptera
	Taragama siva Lef.	Lasiocampidae	Lepidoptera
Leaf butterfly	*Tarucus theophrastus* (F.)	Notodontidae	Lepidoptera
Semilooper	*Achea janata* L.	Noctuidae	Lepidoptera
Leaf caterpillar	*Spodoptera litura* (Fb.)	Noctuidae	Lepidoptera
Hairy caterpillar	*Thiacidas postica* W.	Noctuidae	Lepidoptera
Hairy caterpillar	*Euproctis lunata* Wlk.	Lymantriidae	Lepidoptera
Hairy caterpillar	*E. subnotata* Wlk.	Lymantriidae	Lepidoptera
Hairy caterpillar	*Dasychira moerens* Feld	Lymantriidae	Lepidoptera
	Olene mendosa Hb.	Lymantriidae	Lepidoptera
Tasar silkmoth	*Antheraea paphia* L.	Saturniidae	Lepidoptera
Fruitfly	*Carpomya vesuviana* Costa	Tephritidae	Diptera
	Bactrocera correctus (Bezzi)	Tephritidae	Diptera
	B. dorsalis Hendel	Tephritidae	Diptera
	Adoretus nitidus Arrow	Rutelidae	Coleoptera
	A. pallens Arrow	Rutelidae	Coleoptera
	A. versutus Arrow	Rutelidae	Coleoptera
Leaf defoliator	*Holotrichia insularis* Br.	Melolonthidae	Coleoptera
Spiny beetle	*Platypria andrewsi* W.	Hispidae	Coleoptera
	Celosterna scabrator Fb.	Cerambycidae	Coleoptera
Ber seed weevil	*Aubeus himalayanus* Voss.	Curculionidae	Coleoptera
	Myllocerus discolor (Boheman)	Curculionidae	Coleoptera
	M. maculosus Desbr.	Curculionidae	Coleoptera

	M. transmarinus Hb.	Curculionidae	Coleoptera
	Xanthochelus superciliosus Gyll.	Curculionidae	Coleoptera

SPICES AND CONDIMENTS

Allium cepa (ONION)

Groundnut earwig	*Euborellia annulipes* Lucas	Forficulidae	Dermaptera
Thrips	*Aeolothrips collaris* Priesner	Aeolothripidae	Thysanoptera
Thrips	*Caliothrips indicus* (Bagnall)	Thripidae	Thysanoptera
Thrips	*Thrips tabaci* L.	Thripidae	Thysanoptera
Curworm	*Agrotis ipsilon* Hufn.	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
	Spodoptera exigua (Hb.)	Noctuidae	Lepidoptera
	S. litura F.	Noctuidae	Lepidoptera
	Anthrenus ocenicus Fauvel	Dermestidae	Coleoptera
	A. jordanicus Pic.	Determestidae	Coleoptera
	Alphitobus laevigatus (Fb.)	Tenebrionidae	Coleoptera
Onion fly	*Delia (= Hylemya) antiqua* Meigen	Muscidae	Diptera

Allium sativum (GARLIC)

Thrips	*Aeolothrips collaris* Priesner	Aeolothripidae	Thysanoptera
Thrips	*Caliothrips indicus* (Bagnall)	Thripidae	Thysanoptera
	Thrips tabaci L.	Thripidae	Thysanoptera
	Spodoptera exigua (Hb.)	Noctuidae	Thysanoptera
	S. litura (F.)	Noctuidae	Thysanoptera

Amomum subulatum (LARGE CARDAMOM)

Banana aphid	*Pentalonia nigronervosa* Coq.	Aphididae	Hemiptera
	Rhipiphorothrips cruentatus H.	Thripidae	Thysanoptera
Leaf caterpillar	*Clelea plumbiola* Hmpsn.	Zygaenidae	Lepidoptera
Leaf caterpillar	*Artona chorista* Jordan	Zygaenidae	Lepidoptera

Capsicum annuum (CHILLIES)

Whitefly	*Bemisia tabaci* (Genn.)	Aleyrodidae	Hemiptera
Cowbug	*Tricentrus bicolor* Dist.	Membracidae	Hemiptera
Aphid	*Aphis gossypii* G.	Aphididae	Hemiptera
Leaf aphid	*Myzus persicae* (Sulz.)	Aphididae	Hemiptera
	Caliothrips indicus (Bagnall)	Thripidae	Thysanoptera
Flower thrips	*Frankliniella schultzei* P.	Thripidae	Thysanoptera
Chillies thrips	*Scirtothrips dorsalis* Hood	Thripidae	Thysanoptera
Stem borer	*Euzophera perticella* Rag.	Pyralidae	Lepidoptera
Fruit borer	*Spodoptera exigua* (Hb.)	Noctuidae	Lepidoptera
	S. litura (F.)	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Noctuidae	Lepdoptera
	Holotrichia consanguinea Bl.	Melolonthidae	Coleoptera
	H. insularis Br.	Melolonthidae	Coleoptera

	Anomala bengalensis Bl.	Rutelidae	Coleoptera
Root grub	*Arthrodeis* sp.	Tenebrionidae	Coleoptera
	Monolepta signata Oliv.	Galeuricidae	Coleoptera
	Caryedon serratus	Bruchidae	Coleoptera

Chenopodium alba

Aphid	*Hyalopterus atriplicis*	Aphididae	Hemiptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera

Chenopodium ambrosioides

Coreid bug	*Cletus bipunctatus*	Coreidae	Hemiptera
	Spilarctia obliqua Wlk.	Arctiidae	Lepidoptera

Cinnamomum zeylanicum (CINNAMOM)

Leaf psyllid	*Paurospsylla depressa* C.	Psyllidae	Hemiptera
Pink leafhopper	*Bathrogona* sp.	Cicadellidae	Hemiptera
Whitefly	*Bemisia tabaci* (Genn.)	Aleyrodidae	Hemiptera
Wax scale	*Ceroplastes rubens* Mask.	Coccidae	Hemiptera
Leaf miner	*Conopomorpha civica* Meyr.	Gracillariidae	Lepidoptera
Leaf miner	*Phyllocnistis chrysophthalma* Meyr.	Gracillariidae	Lepidoptera
Citrus leaf miner	*P. citrella* Staint.	Gracillariidae	Lepidoptera
	Zeuzera coffeae Nietn.	Zeuzeridae	Lepidoptera
Leaf roller	*Lopharca* sp. nr. *halidora* Meyr.	Tortricidae	Lepidoptera
Leaf webber	*Orthaga vitalis* Walk.	Noctuidae	Lepidoptera
	Selepa celtis Moore	Noctuidae	Lepidoptera
Shoot and leaf webber	*Sorolopha archimedias* Meyr.	Noctuidae	Lepidoptera
Hairy caterpillar	*Euproctis fraterna* Moore	Lymantriidae	Lepidoptera
Tussock caterpillar	*Olene mendosa* Hb.	Lymantriidae	Lepidoptera
	Argina syringa Cram.	Hypsidae	Lepidoptera
Tiger moth	*Spilarctia obliqua* (Walk.)	Arctiidae	Lepidoptera
Cinnamon butterfly	*Chilasa clytia* L.	Papilionidae	Lepidoptera
	Graphium agamemmon menides F. and F.	Papilionidae	Lepidoptera
	G. sarpedon teredon Felder and Felder	Papilionidae	Lepidoptera
	Hyposidra talaca Walk.	Geometridae	Lepidoptera
Hairy caterpillar	*Cricula trifenestrata* H.	Saturniidae	Lepidoptera
White grub	*Leucopholis pinguis* Burm.	Melolonthidae	Coleoptera
Chafer beetle	*Popillia complanata* N.	Rutelidae	Coleoptera
	Singhala hellari Ohs.	Rutelidae	Coleoptera
Leaf twisting weevil	*Apoderus scitulus* Walk.	Curculionidae	Coleoptera
Cinnamom fruit borer	*Alcides morio* Heller	Curculionidae	Coleoptera
Grey weevil	*Myllocerus subfasciatus* Guen.	Curculionidae	Coleoptera
Red tree ant	*Oecophylla smaragdina* (F.)	Formicidae	Hymenoptera

Coriandrum sativum (CORIANDER)

Grasshopper	*Chondracris rosea* (Degeer)	Acrididae	Orthoptera
Grasshopper	*Ciracris nigricornis* Wlk.	Acrididae	Orthoptera
Whtefly	*Bemisia tabaci* (Gennadius)	Aleyrodidae	Hemiptera
Cooriander aphid	*Hyadaphis coriandri* (Das)	Aphididae	Hemiptera
Plant bug	*Agonoscelis nubila* F.	Pentatomidae	Hemiptera
Cutworm	*Spodoptera exigua* (Hb.)	Noctuidae	Lepidoptera
	Monolepta signata Oliv.	Galeuricidae	Coleoptera

Curcuma longa (TURMERIC)

Turmeric scale	*Aspidiella hartii* C.	Diaspididae	Hemiptera
	A. curcumae Gr.	Diaspididae	Hemiptera
Banana lacewing bug	*Stephanitis typica* D.	Tingidae	Hemiptera
Thrips	*Anaphothrips sudanensis* Trybom	Thripidae	Thysanoptera
	Asprothrips indicus (Bagnall)	Thripidae	Thysanoptera
	Panchaetothrips indicus Bagnall	Thripidae	Thysanoptera
Stem borer	*Conogethes punctiferalis* (Guen.)	Pyralidae	Lepidoptera
Stored rhizome larva	*Ephestia* sp.	Pyralidae	Lepidoptera
	Pyralis manihotalis Guen.	Pyralidae	Lepidoptera
Stored rhizome larva	*Setomorpha rutella* Zell.	Tineidae	Lepidoptera
Leaf caterpillar	*Catopsilia pomona* (F.)	Pieridae	Lepidoptera
Skipper butterfly	*Udaspes folus* Cr.	Hesperiidae	Leipidoptera
	Creatonotus gangis (L.)	Arctiidae	Leipdoptera
Bihar hairy caterpillar	*Spilarctia obliqua* (Wlk.)	Arctiidae	Lepidoptera
Leaf defoliator	*Penicillaria jocosatrix* Gr.	Noctuidae	Lepidoptera
Cigarette beetle	*Lasioderma serricorne* (Fab.)	Anobiidae	Coleoptera
Drug store beetle	*Stegobium paniceum* L.	Anobiidae	Coleoptera
Rhizome beetle	*Araecerus fasciculatus* (Deg.)	Anthribiidae	Coleoptera
Red flour beetle	*Tribolium castaneum* (Hbst.)	Bostrychidae	Coleoptera
White grub	*Holotrichia fissa* Brenske	Scarabaeidae	Coleoptera
Saw toothed beetle	*Oryzaephilus surinamensis* (L.)	Sylvanidae	Coleoptera
	Epilachna sparsa (Hbst.)	Coccinellidae	Coleoptera
Cadelle	*Tenebroides mauritanicus* (L.)	Tenebrionidae	Cleoptera
Leaf beetle	*Ceratobasis nair* Loc.	Eumolpidae	Coleoptera
	Coalaspasoma splendidum (F.)		
	Cryptocephalus rajah Jac.	Eumolpidae	Coleoptera
	Lema lacordairei Baly	Galeuricidae	Coleoptera
	L. praeusta Fabr.	Galeuricidae	Coleoptera
	L. semiregularis Jac.	Galeuricidae	Coleoptera
	L. signatipennis Jac.	Galeuricidae	Coleoptera
	Pseudocophora sp.	Galeuricidae	Coleoptera
Leaf weevil	*Hedychorus rufofasciatus* M.	Curculionidae	Coleoptera
Ash weevil	*Myllocerus viridanus* Fab.	Curculionidae	Coleoptera
Rhizome fly	*Calobata* sp.	Micropezidae	Diptera
Rhizome fly	*Mimegralla coeruleifrons* Macq.	Micropezidae	Diptera
Rhizome fly	*Eumerus pulcherrimus* Bru.	Syrphidae	Diptera

Elletaria cardamomum (CARDAMOM)

Wingless grasshopper	*Orthacris* sp.	Acrididae	Orthoptera
Grasshopper	*Ciracris nigricornis* Wlk.	Acrididae	Orthoptera
Grasshopper	*Oxya hyla hyla* Serville	Acrididae	Orthoptera
Spotted grasshopper	*Aularches miliaris* L.	Acrididae	Orthopetra
Leafhopper	*Tettigoniella ferruginea*	Cicadellidae	Hemiptera
Pink leaf hopper	*Bothrogonia* sp.	Cicadellidae	Hemiptera
Spittle bug	*Aphrophora nuwarana* Dist.	Cercopidae	Hemiptera
Banded spittle bug	*Cosmoscarta thoracica* Dist.	Cercopidae	Hemiptera
Brown spittle bug	*Eosocarta nilgiriensis* Dist.	Cercopidae	Hemiptera
Banana aphid	*Pentalonia nigronervosa* Coq.	Aphididae	Hemiptera
Whitefly	*Aleuroclava cardamomi* David and Sub.	Aleyrodidae	Hemiptera
Cardamom whitefly	*Singhiella cardamomi* (David and Sub.)	Aleyrodidae	Hemiptera
Mealy bug	*Planococcus citri* (Risso)	Pseudococcidae	Hemiptera
	Diaspis sp.	Diaspididae	Hemiptera
	Mytilaspis sp.	Diaspididae	Hemiptera
Black scale	*Parasaissetia nigra* (Nietn.)	Coccidae	Hemiptera
Helmet scale	*Saissetia coffeae* Wlk.	Coccidae	Hemiptera
Helmet scale	*S. nigra* (Walk.)	Coccidae	Hemiptera
	Ischnodemus vochus Tol.	Coccidae	Hemiptera
Banana lacewing bug	*Stephanitis typica* D.	Tingidae	Hemiptera
	Riptortus pedestris F.	Coreidae	Hemiptera
	Leeuwania maculans Pr. and Sesh.	Thripidae	Thysanoptera
Turmeric thrips	*Panchaetothrips indicus* Bagnall	Thripidae	Thysanoptera
Cardamom thrips	*Sciothrips cardamomi* (Ramk.)	Thripidae	Thysanoptera
Bugworm	*Acanthopsyche bipar* Wlk.	Psychidae	Lepidoptera
Stem borer	*Conogethes punctiferalis* (Guen.)	Pyralidae	Lepidoptera
Root borer	*Hilarographa caminodes* Meyr.	Pyralidae	Lepidoptera
Skipper butterfly	*Notocrypta feisthamelii* B.	Hesperiidae	Lepidoptera
Black skipper butterfly	*Plesioneura alysos* M.	Hesperiidae	Lepidoptera
Capsule borer	*Jamides alecta* (Felder)	Lycaenidae	Lepidoptera
Cutworm	*Arcilasisa plagiata* M.	Noctuidae	Lepidoptera
	Lenodera vittata Wlk.	Lasiocampidae	Lepidoptera
	Attacus atlas Linn.	Saturniidae	Lepidoptera
Leaf roller	*Homona* sp.	Tortricidae	Lepidoptera
	Eupterote canaraica M.	Bombycidae	Lepidoptera
	E. cardamomi Ayyar	Bombycidae	Lepidoptera
	E. fabia Cram.	Bombycidae	Lepidoptera
	E. testacea Wlk.	Bombycidae	Lepidoptera
Looper caterpillar	*Anisodes deniticulatus* Hampson	Geometridae	Lepidoptera
	Eumelia rosalia Cram.	Geometridae	Lepidoptera
	Thalassodes sp.	Geometridae	Lepidoptera
	Lampides elpis G.	Lycaenidae	Lepidoptera

Tiger moth	*Alphaea biguttata* Walk.	Arctiidae	Lepidoptera
Black hairy caterpillar	*Pericallia ricini* Fab.	Arctiidae	Lepidoptera
	Euproctis lutifacia Hampson	Lymantriidae	Lepidoptera
Seedling deadheart	*Chlorospisca* sp.	Chloropidae	Lepidoptera
Leaf beetle	*Lema admiralis*	Galerucidae	Coleoptera
	L. coromandeliana	Galerucidae	Coleoptera
Leaf beetle	*Monolepta erythrocephala* Baly.	Galerucidae	Coleoptera
	Thamurgides cardamomi	Galerucidae	Coleoptera
White grub	*Anomala* sp.	Rutelidae	Coleoptera
	Mimela xanthorrhina Hope	Rutelidae	Coleoptera
White grub	*Holotrichia serrata*	Melolonthidae	Coleoptera
	Onthophagus coorgensis	Melolonthidae	Coleoptera
Red flour beetle	*Tribolium castaneum* (Hbst.)	Tenebrionidae	Coleoptera
Leaf weevil	*Astychus lateralis* F.	Curculionidae	Coleoptera
Rhizome weevil	*Prodioctes haematicus* Chev.	Curculionidae	Coleoptera
	Basilepta fulvicorne Jacoby	Eumolpidae	Coleoptera
Root gall midge	*Hallomyia cardamomi* Nayar	Cecidomyiidae	Diptera
Shoot fly	*Formosina flavipes* Mall.	Chloropidae	Diptera

Foeniculum vulgare (FENNEL)

Grasshopper	*Oxya hyla hyla* Serville	Acrididae	Orthoptera
Aphid	*Aphis craccivora* Koch	Aphididae	Hemiptera
Green semilooper	*Trichoplusia ni* (*Hb.*)	Noctuidae	Lepidoptera
Seed wasp	*Systole albipennis* Walker	Eurytomidae	Hymenoptera
Leaf beetle	*Henosepilachna vigintioctopunctata* (Fb.)	Coccinellidae	Coleoptera

Murraya koenigii (CURRYLEAF)

Grasshopper	*Oxya hyla hyla* Serville	Acrididae	Orthoptera
AK grasshopper	*Poekilocerus pictus* F.	Acrididae	Orthoptera
Citrus psyllid	*Diaphorina citri* Kuw.	Psyllidae	Hemiptera
	Phenacoccus iceryoides Gr.	Pseudococcidae	Hemiptera
	Orthezia insignis B.	Ortheziidae	Hemiptera
	Aonidiella orientalis (Newst.)	Diaspididae	Hemiptera
Blackfly	*Aleurocanthus woglumi* Ashby	Aleyrodidae	Hemiptera
	Aleurolobus confusus David and Sub.	Aleyrodidae	Hemiptera
	A. marlatti (Quaintance)	Aleyrodidae	Hemiptera
	A. orientalis David and Jesudasan	Aleyrodidae	Hemiptera
	Trialeurodes ricini (Misra)	Aleyrodidae	Hemiptera
Bark borer	*Indarbela tetraonis* M.	Metarbelidae	Lepidoptera
Leaf roller	*Psorosticha zizyphi* St.	Depressariidae	Lepidoptera
Citrus butterfly	*Papilio demoleus* L.	Papilionidae	Lepidoptera
Tortoise beetle	*Silana farinosa*	Cassididae	Coleoptera

Myristica fragrans (NUTMEG)

Soft scale	*Lecanium psidii*	Coccidae	Hemiptera
Scale insect	*Parasaissetia nigra* (Nietn.)	Coccidae	Hemiptera
	Protopulvinaria mangiferae (Green)	Coccidae	Hemiptera
Scale insect	*Pseudaulacaspis cockerelli* (C.)	Diaspididae	Hemiptera
Jumping bug	*Pauropsylla depressa* C.	Psyllidae	Hemiptera
Rice earhead bug	*Leptocorisa acuta* (Thumb.)	Alydidae	Hemiptera

Nigella sativa L. (CUMIN BLACK)

Grasshopper	*Trilophidia annulata* (Thunb.)	Acrididae	Orthoptera

Pimenta dioica (ALL-SPICE)

Tea mosquito bug	*Helopeltis antonii* Sign	Miridae	Hemiptera

Pimpinella anisum L. (ANISEED)

Aphid	*Aphis gossypii* Koch.	Aphididae	Hemiptera
Green semilooper	*Trichoplusia ni* (Hb.)	Noctuidae	Lepidoptera

Piper nigum (PEPPER)

White tailed mealy bug	*Ferrisia virgata* (Ckll.)	Pseudococcidae	Hemiptera
Mealy bug	*Planococcus citri* (Riso)	Pseudococcidae	Hemiptera
Scale insect	*Aspidiotus destructor* Sign.	Diasphididae	Hemiptera
	Chionaspis raricosa Gr.	Diaspididae	Hemiptera
	Hemichionaspis aspidistrae Sign.	Diaspididae	Hemiptera
	Lepidosaphes piperis Gr.	Diaspididae	Hemiptera
	Pinnaspis aspidistrae S.	Diaspididae	Hemiptera
	P. marchali Ckll.	Diaspididae	Hemiptera
	Marsipococcus marsupiale Gr.	Coccidae	Hemiptera
Blackfly	*Aleurocanthus valpariensis* David and Sub.	Aleyrodidae	Hemiptera
Aphid	*Toxoptera aurantii* (B. de F.)	Aphididae	Hemiptera
	Disphinctus maesarum Kirk	Miridae	Hemiptera
	Helopeltis antonii Sign.	Miridae	Hemiptera
Leafhopper	*Empoasca devastans* Dist.	Cicadellidae	Hemiptera
	Cyclopelta siccifolia Westw	Phlaeothripidae	Thysanoptera
Leaf roll thrips	*Androthrips flavipes* Karny	Phlaeothripidae	Thysanoptera
	Liothrips chavicae Z.	Phlaeothripidae	Thysanoptera
	L. karnyi Bagnall	Phaeothripidae	Thysanoptera
	L. pallipes Karny	Phlaeothripidae	Thysanoptera
Vine shoot borer	*Cydia (= Laspeyresia) hemidoxa* M.	Tortricidae	Lepidoptera
Nettle grub	*Latoia lepida* Cram.	Limacodiidae	Lepidoptera
Slug caterpillar	*Thosea sinensis* Wlk.	Limacodiidae	Lepidoptera
	Cricula trifenestrata H.	Saturniidae	Lepidoptera
Tobacco caterpillar	*Spodoptera litura* F.	Noctuidae	Lepidoptera

Flea beetle	*Hermaeophaga* sp.	Alticidae	Coleoptera
Pollu beetle	*Longitarsus nigripennis* M.	Alticidae	Coleoptera
	Neculla pollinaria B.	Alticidae	Coleoptera
	Pagria costatipennis J.	Alticidae	Coleoptera
	Diboma procera Pasc.	Cerambycidae	Coleoptera
	Pterolophia annulata Chev.	Cerambycidae	Coleoptera
Pepper weevil	*Eugnagthus curvus* Faust	Curculionidae	Coleoptera
Pepper gall midge	*Cecidomyia malabarensis* Felt.	Cecidomyiidae	Diptera

Syzygium aromaticum **(CLOVE)**

Jumping bug	*Pauropsylla depressa* C.	Psyllidae	Hemiptera
Wax scale	*Ceroplastes floridensis* Com.	Coccidae	Hemiptera
Soft scale	*Lecanium psidii*	Coccidae	Hemiptera
Black scale	*Parasaissetia nigra* Nietn.	Coccidae	Hemiptera
Green scale	*Chloropulvinaria psidii* (Mask.)	Coccidae	Hemiptera
Scale insect	*Kilifia acuminata* (Sign.)	Coccidae	Hemiptera
Masked scale	*Mycetaspis personata* (Com.)	Coccidae	Hemiptera
Scale insect	*Aspidiotus destructor* Sign.	Diaspididae	Hemiptera
Chilli thrips	*Scritothrips dorsalis* Hood	Thripidae	Thysanoptera
Teak sapling borer	*Sahyadrassus malabaricus* (Moore)	Hepialidae	Lepidoptera
Coffee stem borer	*Zeuzera coffeae* Nietn.	Zeuzeridae	Lepidoptera
Coffee bean weevil	*Araecerus fasciculatus* De Geer	Anthribiidae	Coleoptera

Trachyspermum ammi **(L.) (AJOWAN)**

Grasshopper	*Oxya hyla hyla* Serville	Acrididae	Orthoptera

Trigonella foenum-graecum **(FENUGREEK)**

Grasshopper	*Ciracris nigricornis* Wlk.	Acrididae	Orthoptera
Aphid	*Aphis craccivora* Koch.	Aphididae	Hemiptera
Aphid	*A. gossypii* G.	Aphididae	Hemiptera
Green semilooper	*Trichoplusia ni* (Hb.)	Noctuidae	Lepidoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Leaf beetle	*Monolepta signata* Oliv.	Galeuricidae	Coleoptera

Zingiber officinale **(GINGER)**

Banan aphid	*Pentalonia nigronervosa* Coq.	Aphididae	Hemiptera
Rhizome scale	*Aspidiella hartii* Ckll.	Coccidae	Hemiptera
Onion thrips	*Thrips tabaci* Lind.	Thripidae	Thysanoptera
Stem borer	*Conogethes punctiferalis* Guen.	Pyralidae	Lepidoptera
Stored rhizome larva	*Setomorpha rutella* Zell.	Tineidae	Lepidoptera
Leaf defoliator	*Spodoptera litura* (F.)	Noctuidae	Lepidoptera
Stored rhizome larva	*Pyralis manihotalis* Guen.	Pyralidae	Lepidoptera
Turmeric skipper	*Udaspes folus* Cr.	Hesperiidae	Lepidoptera
Leaf miner	*Acrocercops irradians* Meyr.	Gracillariidae	Lepidoptera
Stored rhizome larva	*Setomorpha rutella* Zell	Tineidae	Lepidoptera
Leaf defoliator	*Spodoptera litura* (F.)	Noctuidae	Lepidoptera
White grub	*Holotrichia fissa* Brenske	Melolonthidae	Coleoptera
Cigarette beetle	*Lasioderma serricorne* (Fab.)	Anobiidae	Coleoptera

Drug store beetle	*Stegobium paniceum* L.	Anobiidae	Coleoptera
Cadelle	*Tenebroides mauritanicus* (L.)	Tenebrionidae	Coleoptera
Coffee bean weevil	*Araecerus fasciculatus* (Deg.)	Anthribiidae	Coleoptera
Fly maggot	*Chalcidomyia atricornis* M.	Chloropidae	Diptera
	Formosina flavipes M.	Chloropidae	Diptera
Rhizome fly	*Calobata indica*	Micropezidae	Diptera
Rhizome fly	*Mimegralla coeruleifrons* Macq.	Micropezidae	Diptera
Rhizome fly	*Celyphus* sp.	Celyphidae	Diptera
Rhizome fly	*Eumerus albifrons* Wlk.	Syrphidae	Diptera
Rhizome fly	*E. pulcherrimus* Bru.	Syrphidae	Diptera

GREEN MANURES

Calotropis gigantea

"AK" grasshopper	*Poekilocerus pictus* F.	Acrididae	Orthoptera
Calotropis aphid	*Aphis nerii* B deF	Aphididae	Hemiptera
Leafhopper bug	*Eurybrachis tomentosa* F.	Eurybrachidae	Hemiptera
Lygaeid bug	*Spilostethus pandurus* (Scop.)	Lygaeidae	Hemiptera
Leaf caterpillar	*Danais chrysippus* L.	Danaidae	Lepidoptera
Leaf caterpillar	*D. plexippus* L.	Danaidae	Lepidoptera
Woolly bear	*Pericallia ricini* Fb.	Arctiidae	Lepidoptera
Fruitfly	*Leproxyda longistylus* W.	Tephritidae	Diptera
Stem borer	*Monohammus nivosus* W.	Cerambycidae	Coleoptera
Calotropis weevil	*Paramecops farinosa* M.	Curculionidae	Coleoptera

Crotalaria juncea (SUNNHEMP)

	Pinnaspis temporaria Ferris	Diaspididae	Hemiptera
	Bemisia tabaci (Genn.)	Aleyrodidae	Hemiptera
Sunhemp mirid bug	*Ragmus importunitas* Dist.	Miridae	Hemiptera
Stem borer	*Laspeyresia tricentra* M.	Eucosmidae	Lepidoptera
	Etiella zinckenell Treit	Pyralidae	Lepidoptera
	Omiodes indicata (F.)	Pyralidae	Lepidoptera
	Lampides boeticus L.	Lycaenidae	Lepidoptera
	Argina cribraria Clerck	Hypsidae	Lepidoptera
	A. syringa C.	Hypsidae	Lepidoptera
	Spilarctia obliqua (Wlk.)	Arctiidae	Lepidoptera
	Uthetheisa pulchella linn.	Arctiidae	Lepidoptera
	Olene mendosa Hb.	Lymantriidae	Lepidoptera
	Porthesia scintillans (Wlk.)	Lymantriidae	Lepidoptera
Leaf caterpillar	*Ilattia (= Amyna)* octo (Gn.)	Noctuidae	Lepidoptera
	Chrysodeixis eriosoma D.	Noctuidae	Lepidoptera
	Spodoptera litura (F.)	Noctuidae	Lepidoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Pod bruchid	*Bruchus pisorum* L.	Bruchidae	Coleoptera
Flea beetle	*Longitarsus belgaumensis* F.	Alticidae	Coleoptera

Gliricida maculata

	Aphis craccivara Koch.	Aphididae	Hemiptera
	Ferrisia virgata (Ckli.)	Pseudococcidae	Hemiptera
	Eurema blanda silhetana Wallace	Pieridae	Lepidoptera
Hairy caterpillar	*Olene mendosa* Hb.	Lymantriidae	Lepidoptera
Bud weevil	*Indozocladius asperulus* Fst.	Curculionidae	Coleoptera
	Myllocerus discolor F.	Curculionidae	Coleoptera
	M. viridanus F.	Curculionidae	Coleoptera
	Ptochus ovulum Fst.	Curculionidae	Coleoptera

Pongamia glabra (PUNGAM)

Whitefly	*Aleuroclava complex* Singh	Aleyrodidae	Hemiptera
	A. pongamiae Jesusdasan and David	Aleyrodidae	Hemiptera
	Aleurolobus niloticus Pr. and Hos.	Aleyrodidae	Hemiptera
	Aleuromarginatus kallarensis D & S	Aleyrodidae	Hemiptera
	Bemisia pongamiae Takahashi	Aleyrodidae	Hemiptera
Scale insect	*Inglisia bivalvata* Gr	Coccidae	Hemiptera
Lac insect	*Kerria loacca* (Kerr.)	Kerridae	Hemiptera
	Coptosoma cribraria F.	Corimelaenidae	Hemiptera
	Cyclopelta siccifolia Wesh.	Pentatomidae	Hemiptera
	Halys dentatus Fb.	Pentatomidae	Hemiptera
	Megymenum brevicornis Fabr.	Pentatomidae	Hemiptera
Plant bug	*Chrysocoris stollii* (Wolff.)	Scutelleridae	Hemiptera
Pod borer	*Lemoria* sp.	Pyralidae	Lepidoptera
Leaf webber	*Maruca ambionalis*	Pyralidae	Lepidoptera
Leaf miner	*Acrocercops anthracuria*	Gracillariidae	Lepidoptera
Leaf miner	*Lithocolletis vigrulata*	Gracillariidae	Lepidoptera
Blue butterfly	*Curetis thetis* F.	Lycaenidae	Lepidoptera
Skipper	*Parata alexis* F.	Hesperiidae	Lepidoptera
Leaf gall midge	*Asphondylia pongamiae* F.	Cecidomyiidae	Diptera

Ipomoea carnea

Tortoise beetle	*Aspidomorpha miliaris* F.	Cassididae	Coleoptera
	Chrida bipunctata F.	Cassididae	Coleoptera
	Metriona circumdata H.	Cassididae	Coleoptera
Green leaf beetle	*Colasposoma metallicum* C.	Eumolpidae	Coleoptera

Sesbania bispinosa (DAINCHA)

	Coptosoma cribraria F.	Plataspididae	Hemiptera
	Piezodorus rubrofasciatus	Pentatomidae	Hemiptera
	Riptortus pedestris	Coreidae	Hemiptera
Stem borer	*Azygophleps scalaris* Fb.	Zeuzeridae	Hemiptera
Leaf webber	*Striglina scitaria* Wlk.	Thyrididae	Lepidoptera
	Catopsilia pyranthe L.	Pieridae	Lepidoptera
Thrips	*Caliothrips indicus* Bagnall	Thripidae	Thysanoptera

	Eurema blanda silhetana Wallace	Pieridae	Lepidoptera
	Terias hecabe var. *contubernalis* L.	Pieridae	Lepidoptera
Hairly caterpillar	*Porthesia scintillans* Wlk.	Lymantriidae	Lepidoptera
Looper caterpillar	*Semiothisa pervolgata* Wlk.	Geometridae	Lepidoptera
	Hyposidra successaria Wlk.	Geometridae	Lepidoptera
	Grammodes stolida F.	Noctuidae	Lepidoptera
	Pericyma glaucinans	Noctuidae	Lepidoptera
	Spodoptera exigua (Hb.)	Noctuidae	Lepidoptera
	S. litura (F.)	Noctuidae	Lepidoptera
Seed wasp	*Bruchophagus mellipes* G.	Eurytomidae	Hymenoptera
Stem weevil	*Alcidodes bubo* F.	Curculionidae	Coleoptera

Sesbania speciosa

Leafhopper	*Empoasca* sp.	Cicadellidae	Hemiptera
	Aphis craccivora Koch.	Aphididae	Hemiptera
	Brachyplatys vauhlii F.	Plataspididae	Hemiptera
	Coptosoma cribraria F.	Plataspididae	Hemiptera
	Cyclopelta siccifolia Westw.	Pentatomidae	Hemiptera
Stem borer	*Azygophleps scalaris* Fb.	Zeuzeridae	Lepidoptera
	Hyposidra successaria	Geometridae	Lepidoptera
	Pericyma glaucinans	Noctuidae	Lepidoptera
	Spodoptera litura (F.)	Noctuidae	Lepidoptera
	Olene mendosa Hb.	Lymantriidae	Lepidoptera
	Alcidodes bubo F.	Curculionidae	Coleoptera

Tephrosia purpurea

	Aleurolobus niloticus Pr. and Hos.	Aleyrodidae	Hemiptera
Aleyrodid	*Aleuromarginatus tephrosiae* Corbett	Aleyrodidae	Hemiptera
	Bemisia afer (Pr. and Hos.)	Aleyrodidae	Hemiptera
	Zaphanera publicus (Singh)	Aleyrodidae	Hemiptera
Leaf tingid	*Phenotropis cleopatra* Dist.	Tingidae	Hemiptera
Shoot caterpillar	*Dactylethra candida* St.	Gelechiidae	Lepidoptera
Pod borer	*Etiella zinckenella* Treit	Pyralidae	Lepidoptera
Pod midge	*Asphondylia tephrosiae* Mani	Cecidomyiidae	Diptera
	Araecerus fasciculatus DeG.	Anthribiidae	Coleoptera
	Apion sp.	Apionidae	Coleoptera

ORNAMENTAL PLANTS

Althaea rosea (HOLLYHOCK)

	Empoasca devastans Distant	Cicadellidae	Hemiptera
	Aphis gossypii G.	Aphididae	Hemiptera
	Bemisia tabaci (Genn.)	Aleyrodidae	Hemiptera
	Oxycarenus hyalinipennis Costa	Lygaeidae	Hemiptera
	Dysdercus cingulatus (Fb.)	Pyrrhocoridae	Hemiptera
	D. koenigii (Fab.)	Pyrrhocoridae	Hemiptera

	Pectinophora gossypiella Saund.	Gelechiidae	Lepidoptera
	Conogethes punctiferalis Guen.	Pyralidae	Lepidoptera
	Syllepte derogata Fb.	Pyralidae	Lepidoptera
	Earias insulana Boisd.	Noctuidae	Lepidoptera
	E. vittella (F.)	Noctuidae	Lepidoptera
Painted lady butterfly	*Vanessa cardui* (Linn.)	Nymphalidae	Lepidoptera
Skipper butterfly	*Spialia galba galba* (Fabricius)	Hesperiidae	Lepidoptera
Tussock caterpillar	*Olene mendosa* Hb.	Lymantriidae	Lepidoptera
	Euproctis virgincula Walker	Lymantriidae	Lepidoptera
	Craspedoxantha octopunctata Bez.	Tephritidae	Diptera
	Alcidodes affaber Aurv.	Curculionidae	Coleoptera
	Pempherulus affinis Fst.	Curculionidae	Coleoptera
Leaf and Flower beetle	*Nisotra nigripennis* Jacoby	Chrysomelidae	Coleoptera

Antrrhinum majus Linn. (ANTIRRHINUM)

	Oxycetonia albopunctata (Fab.)	Cetoniidae	Coleoptera

Barleria cristata

Wingless grasshopper	*Neorthacris simulans* B.	Acrididae	Orthoptera
Cotton aphid	*Aphis gossypii* G.	Aphididae	Hemiptera
	Icerya sp.	Margarodidae	Hemiptera
	Orthezia insignis D.	Ortheziidae	Hemiptera
	Saissetia hemisphaerica (Targ.)	Coccidae	Hemiptera
	Cerococcus hibisci Gr.	Asterolecaniidae	Hemiptera
Brown leafhopper	*Neodartus scutellatus* Dist.	Cicadellidae	Hemiptera
	Ragmus improtunitas D.	Miridae	Hemiptera
	Habrochila laeta Drake	Tingidae	Hemiptera
	Carbula biguttata Fabr.	Pentatomidae	Hemiptera
	C. socia Wlk.	Pentatomidae	Hemiptera
	Gynencia affinis Dist.	Pentatomidae	Hemiptera
	Piezodorus rubrofasciatus F.	Pentatomidae	Hemiptera
Bud worm	*Trichoptilus* sp. nr. *congrualis* Walk.	Pterophoridae	Lepidoptera
Leaf folder	*Syngamia latimarginalis* Walk.	Pyralidae	Lepidoptera
Leaf webber	*Cacoecia epicyrta* M.	Tortricidae	Lepidoptera
Loopers	*Craspedia* sp.	Geomertidae	Lepidoptera
	Junonia almana	Nymphalidae	Lepidoptera
	J. atlites	Nymphalidae	Lepidoptera
	J. hierta F.	Nymphalidae	Lepidoptera
	J. lemonias Linn.	Nymphalidae	Lepidoptera
	J. orithya Linn.	Nymphalidae	Lepidoptera
Leaf caterpillar	*Eustrotia mianoides* Hmpsn.	Noctuidae	Lepidoptera
	Euproctis fraterna M.	Lymantriidae	Lepidoptera
Leaf miner	*Pseudonapomyza alternanthera* (Segur)	Agromyzidae	Diptera
	Trachys sp.	Buprestidae	Coleoptera
	Myllocerus discolor F.	Curculionidae	Coleoptera

Barleria prionitis

Wingless grasshopper	*Neorthacris simulans* B.	Acrididae	Orthoptera
	Saissetia hemisphaerica (Targ.)	Coccidae	Hemiptera
	Aleurolobus niloticus Pr. and H.	Aleyrodidae	Hemiptera
	Carbula socia Walk.	Pentatomidae	Hemiptera
	Gynencia affinis Dist.	Pentatomidae	Hemiptera
	Nezara viridula Linn.	Pentatomidae	Hemiptera
Green caterpillar	*Lamprosema* sp	Pyralidae	Lepidoptera
Bud worm	*Trichoptilus* sp. *nr. congrualis* Wlk.	Pterophroridae	Lepidoptera
Leaf caterpillar	*Junonia hierta* F.	Nymphalidae	Lepidoptera

***Begonia* sp. (BEGONIA)**

	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera

***Celosia argentea cristata* Linn. (CELOSIA)**

Grasshopper	*Atractomorpha crenulata* Feb.	Acrididae	Orthoptera
	Haplothrips ganglbaurei Schmutz	Phlaeothripidae	Thysanoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera

***Centaurea cyanus* Linn. (CORNFLOWER)**

	Oxycarenus hyalinipennis Costa	Lygaeidae	Hemiptera
	Thrips flavus Schrank	Thripidae	Thysanoptera
Leaf miner	*Chromatomyia horticola* (Gour)	Agromyzidae	Diptera

***Chlorophytum comosum* Wood (CHLOROPHYTUM)**

	Aphis gossypii Glov.	Aphididae	Hemiptera

***Coleus blumei* Kenth (COLEUS)**

	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
Leaf webber	*Aripana (= Pycnarmon) caberalis* Guenee	Pyralidae	Lepidoptera

***Coleus officinalis* Linn. (CALENDULA)**

Shoot aphid	*Aphis citricola* van der Goot	Aphididae	Hemiptera
	Thrips flavus Schrank	Thripidae	Thysanoptera
	Thysanoplusia orichalcea (Fab.)	Noctuidae	Lepidoptera

***Consolida arevensis Opiz.* (LARKSPUR)**

	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera

***Crinum* sp. (LILY)**

Lily caterpillar	*Brithys crini* Fb.	Noctuidae	Lepidoptera
	Polytela gloriosae F.	Noctuidae	Lepidoptera

Crossandra undulaefolia

Leaf scale insect	*Temnaspidiotus excisus* (Gr.)	Diaspididae	Hemiptera
Tussock caterpillar	*Olene mendosa* Hb.	Lymantriidae	Lepidoptera

Chrysanthemum morifolium Ram. (CHRYSANTHEMUM)

	Atractomorpha crenulata Fab.	Acrididae	Orthoptera
	Coloradoa rufomaculata (Wilson)	Aphididae	Hemiptera
	Macrosiphoniella sanborni (Gill)	Aphididae	Hemiptera
Greenhouse whitefly	*Trialeurodes vaporariorum* (Westwood)	Aphididae	Hemiptera
	Cadmilos retiarius Dist.	Tingidae	Hemiptera
	Galeatus scrophilus Saunders	Tingidae	Hemiptera
	Oxycarenus hyalinipennis Costa	Lygaeidae	Hemiptera
Compositae thrips	*Microcephalothrips adbominalis* (Crawf.)	Thripidae	Thysanoptera
	Haplothrips remakrishnae K.	Phlaeothripidae	Thysanoptera
	Omiodes indicata (F.)	Pyralidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
	Plusia nigrisigna Walk.	Noctuidae	Lepidoptera
	Alcidodes fabricii (Fab.)	Curculionidae	Coleoptera
	Mylabris mecilenta Marshal	Meloidae	Coleoptera
	M. phaleratea Pall.	Meloidae	Coleoptera
	M. pustulata Thunb.	Meloidae	Coleoptera
	Altica sp.	Alticidae	Coleoptera
	Chromatomyia horticola (Gour)	Agromyzidae	Diptera

Chrysanthemum segetum Linn. (CHRYSANTHEMUM)

	Oxycarenus hyalinipennis Costa	Lygaeidae	Hemiptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera

Dhalia variabilis (DHALIA)

Surface grasshopper	*Atractomorpha crenulata* Fab.	Acrididae	Orthoptera
Thrips	*Megalurothrips distalis* (Karny)	Thripidae	Thysanoptera
	Microcephalothrips abdominalis (Crawf.)	Thripidae	Thysanoptera
	Thrips hawiiensis	Thripidae	Thysanoptera
Semilooper caterpillar	*Thysanoplusia orichalcea* Fb.	Noctuidae	Lepidoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
Flower beetle	*Oxycetonia albopunctata* (Fab.)	Cetoniidae	Coleoptera
	Mylabris mecilenta Marshal	Meloidae	Coleoptera
	Monolepta signata Oliv.	Galeuricidae	Coleoptera
	Phyllotreta downesi Baly	Galeuricidae	Coleoptera

Dianthus Barbatus Linn. (SWEET WILLIAMS)

Thrips	*Haplothrips coloratus* (Trybom)	Phlaeothripidae	Thysanoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera

Dianthus Caryophyllus Linn. (CARNATION)

Surface grasshopper	*Atractomorpha crenulata* Fab.	Acrididae	Orthoptera

	Thrips flavus Schrank	Thripidae	Thysanoptera
	T. hawaiiensis	Thripidae	Thysanoptera
	Haplothrips coloratus (Trybom)	Phaeothripidae	Thysanoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera
	Mylabris phalerata Pall.	Meloidae	Coleoptera

Gladiolus sp. (GLADIOLUS)

Thrips	*Thrips hawaiiensis*	Thripidae	Thysanoptera
Flower beetle	*Mylabris phalerata* Pall.	Meloidae	Coleoptera
Flower beetle	*M. pustulata* Thunb.	Meloidae	Coleoptera

Hibiscus syriacus (HIBISCUS)

Green grasshopper	*Atractomorpha crenulata crenulata*	Acrididae	Orthoptera
	A. obscura	Acrididae	Orthoptera
Wingless grasshopper	*Neorthacris simulans* B.	Acrididae	Orthoptera
	Cyrtacanthacris ranacea	Acrididae	Orthoptera
	Thrips hawaiiensis	Thripidae	Thysanoptera
	Haplothrips coloratus (Trybom)	Phlaeothripidae	Thysanoptera
Spiralling whitefly	*Aleurodicus dispersus* Russell	Aleyrodidae	Hemiptera
Mealy bug	*Maconellicoccus hirsutus* (Green)	Pseudococcidae	Hemiptera
	Dysdercus cingulatus (Fab.)	Lygaeidae	Hemiptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
Flower beetle	*Oxycetonia albopunctata* (Fab.)	Cetoniidae	Coleoptera
Flower beetle	*Mylabris phalerata* Pall.	Meloidae	Coleoptera
Flower beetle	*M. pustulata* Thunb.	Meloidae	Coleoptera
Leaf beetle	*Hyphasoma discipennis* Jacoby	Chrysomelidae	

Impatiens balsamina (BALSAM)

	Syllepte (= Sylepta) textalis L.	Pyralidae	Lepidoptera
	Theretra oldenlendidae oldenlendidae	Sphingidae	Lepidoptera
	Galerucida bicolor H.	Galerucidae	Coleoptera

Jasminum spp. (JASMINE)

Wingless grasshopper	*Neorthacris simulans* B.	Acrididae	Orthoptera
	Aleurolobus bidentatus Singh	Aleyrodidae	Hemiptera
	Aleurotrachelus coimbatorensis D. and S.	Aleyrodidae	Hemiptera
	Bemisia giffardi (Kotinsky)	Aleyrodidae	Hemiptera
	Dialeurodes kirkaldyi (Kotinsky)	Aleyrodidae	Hemiptera
	Kanakarajiella vulgaris (Singh)	Aleyrodidae	Hemiptera
	Ferrisia virgata Ckil.	Pseudococcidae	Hemiptera
	Phenacoccus ornatus Gr.	Pseudococcidae	Hemiptera
	Lepidosaphes sp.	Diaspididae	Hemiptera
	Parlatoria calianthima Ber and Len	Diaspididae	Hemiptera
Lantana bug	*Orthezia insignis* B.	Ortheziidae	Hemiptera

Green plant hopper	*Flata ocellata* Fb.	Flatidae	Hemiptera
Brown plant hopper	*Ricania fenestrata* Fb.	Ricaniidae	Hemiptera
Jasmine lacewing bug	*Corythauma ayyari* (Drake)	Tingidae	Hemiptera
	Antestiopis cruciata (F.)	Pentatomidae	Hemiptera
	Bathrips jasminae Anan.	Thripidae	Thysanoptera
Leaf thrips	*Dendrothrips jasminum* (R. and M.)	Thripidae	Thysanoptera
	Thrips hawaiiensis (Morgan)	Thripidae	Thysanoptera
	Thrips orientalis (Bagn.)	Thripidae	Thysanoptera
Thrips	*Eothrips coimbatorensis* Ramk.	Phlaeothripidae	Thysanoptera
Thrips	*Eurynchothrips ordinarius* Hood	Phlaeothripidae	Thysanoptera
Flower thrips	*Haplothrips ceylonicus* Schm.	Phlaeothripidae	Thysanoptera
	H. ganglbaueri Sch.	Phlaeothripidae	Physanoptera
	H. veroniae Priesner	Phlaeothripidae	Thysanoptera
Leaf roller	*Psorosticha* sp.	Depressariidae	Lepidoptera
Leaf miner	*Phyllocnistis* sp.	Gracillariidae	Lepidoptera
	Eucosma sp.	Eucosmidae	Lepidoptera
	Laspeyresia koenigana M.	Eucosmidae	Lepidoptera
Bud and shoot worm	*Elasmopalpus jasminophagus* Hmpsn.	Pyralidae	Leipidoptera
Budworm	*Hendecasis duplifascialis* Hmpsn.	Pyralidae	Lepidoptera
Leaf caterpillar	*Glyphodes celsalis* Wlk.	Pyralidae	Lepidoptera
	G. unionalis F.	Pyralidae	Lepidoptera
Webworm	*Nausinoe geometralis* Guen.	Pyralidae	Lepidoptera
	N. neptis Cram.	Pyralidae	Lepidoptera
Hornworm	*Acherontia styx* Westw.	Sphingidae	Lepidoptera
Blossom midge	*Contarinia maculipennis* Felt.	Cecidomyiidae	Diptera
Shoot borer	*Sycophila* sp.	Eurytomidae	Hymenoptera

Lathyrus odoratus Linn. (SWEET PEA)

Thrips	*Megalurothrips distalis* (Karny)	Thripidae	Thysanoptera
	Thrips flavus Schrank	Thripidae	Thysanoptera
	T. hawaiiensis Morgan	Thripidae	Thysanoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
	Plusia nigrisignata Wlk.	Noctuidae	Lepidoptera

Michelia champaca (CHAMPACA)

Whitefly	*Aleurocanthus rugosa* Singh	Aleyrodidae	Hemiptera
Spiralling whitefly	*Aleurodicus dispersus* Russel	Aleyrodidae	Hemiptera
Whitefly	*Taiwanaleyrodes indica* (Singh)	Aleyrodidae	Hemiptera
Swallow tailed butterfly	*Graphium agamemnon menides* F. and F.	Papilionidae	Lepidoptera

Nerium odorum (OLEANDER)

	Nipaecoccus vastator Mask.	Pseudococcidae	Hemiptera
	Aspidiotus transparens Gr.	Diaspididae	Hemiptera
Indian crow butterfly	*Euploea core* C.	Danaidae	Lepidoptera
Looper caterpillar	*Agathia hemithearia* Guen.	Geometridae	Lepidoptera

	A. lactata F.	Geometridae	Lepidoptera
Wooly bear	*Pericallia ricini* F.	Arctiidae	Lepidoptera
Oleander hawk moth	*Daphnis nerii* L.	Sphingidae	Lepidoptera
Stem girdler	*Sthenias grisator* Fb.	Cerambycidae	Coleoptera

Nyctanthes arbortristis **(PARIJATH)**

Hairy caterpillar	*Metanastria hyrtaca* C.	Lasiocampidae	Lepidoptera
Horned caterpillar	*Psilogramma memephron* Cr.	Sphingidae	Lepidoptera
Semilooper	*Eublemma silicula* Swinhoe	Noctuidae	Lepidoptera

Papaver orientale **Linn. (ORIENTAL POPPY)**

	Thrips flavus Schrank	Thripidae	Thyasanoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
Leaf miner	*Chromatomyia horticola* (Gour)	Agromyzidae	Diptera

Papaver paniculata **Linn. (PHLOX)**

Thrips	*Thrips flavus* Schrank	Thripidae	Thysanoptera
Leaf miner	*Chromatomyia horticola* (Gour)	Agromyzidae	Diptera

Polianthes tuberosa **Linn. (TUBEROSA)**

Flower beetle	*Mylabris phalerata* Pall.	Meloidae	Coleoptera

Quisqualis indica **(RANGOON CREEPER)**

Leaf roller	*Striglina scitaria* Wlk.	Thripidae	Lepidoptera
Flower caterpillar	*Rapala varuna* Horsfield	Lycaenidae	Lepidoptera
Leaf caterpillar	*Anua coronata* Fb.	Noctuidae	Lepidoptera
	Othreis fullonica Linn.	Noctuidae	Lepidoptera
	O. materna Linn.	Noctuidae	Lepidoptera
Leaf weevil	*Myllocerus viridanus* F.	Curculionidae	Coleoptera

Rosa sp. **(ROSE)**

AK grasshopper	*Poekilocerus pictus* F.	Acrididae	Orthoptera
Cow bug	*Leptocentrus obliquus* W.	Membracidae	Hemiptera
	Tricentrus bicolor Dist.	Membracidae	Hemiptera
Leafhopper	*Empoasca* sp.	Cicadellidae	Hemiptera
Aleyrodid	*Aleurocanthus spiniferus* Q.	Aleyrodidae	Hemiptera
	Aleurolobus niloticus Pr. and Hosn.	Aleyrodidae	Hemiptera
	Aleurotrachelus caerulescens Singh.	Aleyrodidae	Hemiptera
	Dialeuropora decempuncta (Q. and B.)	Aleyrodidae	Hemiptera
Greenhouse whitefly	*Trialeurodes vaporariorum* (Westwood)	Aleyrodidae	Hemiptera
	Icerya aegyptiaca Dougl.	Margarodidae	Hemiptera
	I. purchasi Mask.	Margarodidae	Hemiptera
	Saissetia hemisphaerica (Targ.)	Coccidae	Hemiptera
	Aonidiella orientalis (Newst.)	Diaspididae	Hemiptera
	A. aurantii (Mask.)	Diaspididae	Hemiptera

	Aspidiotus transparens Gr.	Diaspididae	Hemiptera
	Chionaspis sp.	Diaspididae	Hemiptera
	Lindingaspis rossi	Diaspididae	Hemiptera
	Chaetosiphon tetrapodes Walker	Aphididae	Hemiptera
	Macrosiphum euphorbiae Thomas	Aphididae	Hemiptera
	M. rosae L.	Aphididae	Hemiptera
	M. rosaeformis D.	Aphididae	Hemiptera
	Rhodobium porosum Sand	Aphididae	Hemiptera
	Lefroyothrips lefroyi (Bagnl.)	Thripidae	Thysanoptera
	Megalurothrips distalis (Karny)	Thripidae	Thysanoptera
	Microcephalothrips abdominalis (Crawf.)	Thripidae	Thysanoptera
	Retithrips syriacus (Mayet)	Thripidae	Thysanoptera
	Rhipiphorothrips cruentatus Hood	Thripidae	Thysanoptera
	Taeniothrips flavus Ananth. and Jagdish	Thripidae	Thysanoptera
	Thrips coloratus Priesner	Thripidae	Thysanoptera
	T. flavus Schr.	Thripidae	Thytsanoptera
	T. hawaiiensis (Morgan)	Thripidae	Thysanoptera
	Haplothrips coloratus (Trybom)	Phlaeothripidae	Thysanoptera
Stem borer	*Sahyadrussus malabaricus* M.	Hepialidae	Lepidoptera
Bagworm	*Eumeta crameri* (Westw.)	Psychidae	Lepidoptera
Bark borer	*Indarbela tetraonis* M.	Metarbelidae	Lepidoptera
Slug caterpillar	*Latoia lepida* C.	Limacodiidae	Lepidoptera
Leaf roller	*Argyroploce aprobola* Meyr.	Eucosmidae	Lepidoptera
Tent caterpillar	*Malacosoma indica* Wlk.	Lasiocampidae	Leipdoptera
	Taragama siva Lef.	Lasiocampidae	Lepidoptera
	Trabal vishnou L.	Lasiocampidae	Lepidoptera
	Stauropus alternus W.	Notodontidae	Lepidoptera
	Achaea janata Linn.	Noctuidae	Lepidoptera
Tobacco caterpillar	*Spodoptera litura* (Fb.)	Noctuidae	Lepidoptera
Hairy caterpillar	*Euproctis fraterna* M.	Lymantriidae	Lepidoptera
	Olene mendosa Hb.	Lymantriidae	Lepidoptera
	Dasychira moerens Feld	Lymantriidae	Lepidopera
	D. grotei M.	Lymantriidae	Lepidopera
	Orgyia postica (Wlk.)	Lymantriidae	Lepidopera
	Porthesia scintillans W.	Lymantriidae	Lepidopera
	Allodape parvula Sm.	Apidae	Hymenoptera
Leaf cutter bee	*Ceratina binghami* Ckll.	Apidae	Hymenoptera
	Megachile anthracina S.	Megachilidae	Hymenoptera
	Arge fumipennis Sm.	Argidae	Hymenoptera
Flower chafer beetle	*Oxycetonia albopunctata* (Fab.)	Cetoniidae	Coleoptera
	O. versicolor F.	Cetoniidae	Coleoptera
	Anomala sp.	Rutelidae	Coleoptera
Flower beetles	*Adoretus versutus* H.	Rutelidae	Coleoptera
	Popillia complanta Newm.	Rutelidae	Coleoptera
	P. schizonycha Arrow	Rutelidae	Coleoptera
	Mylabris pustulata Th.	Meloidae	Coleoptera

	Maladera insanabilis (Brenske)	Scarabaeidae	Coleoptera
Stem girdler	*Sthenias grisator* F.	Ceramybycidae	Coleoptera
Leaf beetle	*Myllocerus undecimpustulatus* Faust	Curculionidae	Coleoptera

Tagetes erecta Linn. (MARIGOLD)

Surface grasshopper	*Atractomorpha crenulata* Fab.	Acrididae	Orthoptera
Flower thrips	*Microcephalothrips abdominalis* (Crawf.)	Thripidae	Thysanoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Leipdoptera
Serpentine leaf miner	*Liriomyza trifolii* (Burgess)	Agromyzidae	Diptera

Tropaeolum majus Linn. (NASTURTIUM)

	Thrips flavus Schrank	Thripidae	Thysanoptera
Leaf caterpillar	*Pieris rapae* Linn.	Pieridae	Lepidoptera
Leaf miner	*Chromatomyia horticola* (Gour)	Agromyzidae	Diptera
Leaf miner	*Liriomyza brassicae* (Riley)	Agromyzidae	Diptera

Zinnia elegans Jacq. (ZINNIA)

AK grasshopper	*Poekilocerus pictus* F.	Acrididae	Orthoptera
Flower thrips	*Microcephalothrips abdominalis* (Crawf.)	Thripidae	Thysanoptera

BEVERAGES

Camellia sinensis (TEA)

Desert locust	*Schistocerca gregaria* Forsk.	Acrididae	Orthoptera
Dark brown cricket	*Brachytrypes portentosus* Licht.	Gryllidae	Orthoptera
Mole cricket	*Gryllotalpa africana P.* deB	Gryllotalpidae	Orthoptera
	Orthacris incongruens Carl.	Pyrgomorphidae	Orthoptera
	O. robusta Kevan	Pyrgomorphidae	Orthoptera
	Microtermes spp.	Termitidae	Isoptera
	Odontorermes assamensis Holm.	Termitidae	Isoptera
	O. parvidens K. and N. Holm.	Termitidae	Isoptera
	Microcerotermes sp.	Termitidae	Isoptera
	Empoasca flavescens Fabr.	Cicadellidae	Hempitera
Moth bug	*Lawana conspersa* Wlk.	Flatidae	Hemiptera
Tea aphid	*Toxoptera aurantii* Boyer	Aphididae	Hemiptera
	Ceroplastes rubens (Maskell)	Coccidae	Hemiptera
	C. floridensis Comstock	Coccidae	Hemiptera
	C. cerifera (Anderson)	Coccidae	Hemiptera
	Ceroplastodes cajani (Maskell)	Coccidae	Hemiptera
	C. chiton (Green)	Coccidae	Hemiptera
	Coccus discrepans (Green)	Coccidae	Hemiptera
Soft brown scale	*C. hesperidum* L.	Coccidae	Hemiptera
	C. viridis (Green)	Coccidae	Hemiptera
	Eriochiton theae (Green)	Coccidae	Hempitera
	Eucalymnatus tessellatus (Signoret)	Coccidae	Hemiptera

	Nipaecoccus viridis (Newstead)	Coccidae	Hemiptera
	Parasaissetia nigra (Nietner)	Coccidae	Hemiptera
	Saissetia coffeae Wlk.	Coccidae	Hemiptera
	S. hemisphaerica (Targ.)	Coccidae	Hemiptera
	S. oleae (Barnard)	Coccidae	Hemiptera
Black scale	*S. formicarii* (Green)	Coccidae	Hemiptera
	S. watti (Green)	Coccidae	Hemiptera
	Andaspis sp.	Diaspididae	Hemiptera
	Aonidiella aurantii (Maskell)	Diaspididae	Hemiptera
	A. orientalis (Newstead)	Diaspididae	Hemiptera
	Aspidiotus destructor (Signoret)	Diaspididae	Hemiptera
	Chionaspis separata Green	Diaspididae	Hemiptera
	Chrysomphalus pinnulifer (Maskell)	Diaspididae	Hemiptera
	Fiorinia theae Green	Diaspididae	Hemiptera
	Hemiberlesia lataniae (Signoret)	Diaspididae	Hemiptera
	H. rapax (Comstock)	Diaspididae	Hemiptera
	Lindingaspis ferrisi (McKenzie)	Diaspididae	Hemiptera
	Morganella longispina (Morgan)	Diaspididae	Hemiptera
	Phenacaspis manni (Green)	Diaspididae	Hemiptera
	Parlatoria proteus (Curtis)	Diaspididae	Hemiptera
	Pinnaspis theae (Maskell)	Diaspididae	Hemiptera
	Pseudaonidia duplex (Ckll.)	Diaspididae	Hemiptera
	Velataspis serrulata Ganguli	Diaspididae	Hemiptera
	Cataenococcus theaecola (Green)	Pseudococcidae	Hemiptera
	Crisicoccus sp.	Pseudococcidae	Hemiptera
Root mealy bug	*Dysmicoccus* sp.	Pseudococcidae	Hemiptera
	Nipaecoccus vastator (Maskell)	Pseudococcidae	Hemiptera
Tea mosquito bug	*Helopeltis theivora* Waterl	Miridae	Hemiptera
	Pachypeltis humeralis (W.)	Miridae	Hemiptera
Tea seed bug	*Poecilocoris latus* Dall	Pentatomidae	Hemiptera
	Lefroyothrips lefroyi (Bagn.)	Thripidae	Thysanoptera
	Scirtothrips bispinosus (Bagnall)	Thripidae	Thysanoptera
	S. dorsalis Hood	Thripidae	Thysanoptera
	Mycterothrips setiventris (Bagn.)	Thripidae	Thysanoptera
	Thrips flavus Schm.	Thripidae	Thysanoptera
	T. hawaiiensis (Morgan)	Thripidae	Thysanoptera
	Haplothrips andresi Priesner	Phlaeothripidae	Thysanoptera
Black thrips	*H. tenuipennis* Bag.	Phlaeothripidae	Thysanoptera
Stem borer	*Sahyadrussus malabaricus* M.	Hepialidae	Lepidoptera
Large stem borer	*Casmara patrona* Meyr.	Oecophoridae	Lepidoptera
	Odites sp.	Cryptophasidae	Lepidoptera
Tea leafroller	*Caloptilia (= Gracillaria) theivora* Wlsm.	Gracillariidae	Lepidoptera
Yellow bark eating caterpillar	*Comocritis pieria* Meyr.	Plutellidae	Lepidoptera
Sandwich caterpillar	*Agriophora rhombata* Meyr.	Tinaeidae	Lepidoptera
Gazipore bark eating caterpillar	*Ptochoryctis simplenta* Meyr.	Tinaeidae	Lepidoptera

Common red borer	*Zeuzera coffeae* Niet.	Zeuzeridae	Lepidoptera
	Brachycyttarus subtalbata Hmps.	Psychidae	Lepidoptera
Limpet caterpillar	*Cathopsyche reidi* Watt.	Psychidae	Lepidoptera
	Chaloides ferevitrea Joan	Psychidae	Lepidoptera
	C. vitrea Hmps.	Psychidae	Lepidoptera
	Clania antrami Hmps.	Psychidae	Lepidoptera
Small faggot worm	*C. destructor* Dudg.	Psychidae	Lepidoptera
	C. mahanti Das	Psychidae	Lepidoptera
Bagworm	*C. sikkima* Moore	Psychidae	Lepidoptera
	C vaulogeri Heyl.	Psychidae	Lepidoptera
	Dappula tertius Templ.	Psychidae	Lepidoptera
Large faggot worm	*Eumetes crameri* (Westwood)	Psychidae	Lepidoptera
Basketworm	*Mahasena theivora* Dudg.	Psychidae	Lepidoptera
Conical psychid	*Manatha assamica* Watt.	Psychidae	Lepidoptera
Leaf perforator	*Metisa plana* Wlk.	Psychidae	Lepidoptera
Triangular faggot worm	*Orophora triangularis* Das	Psychidae	Lepidoptera
	Oiketicoides bipas Wlk.	Psychidae	Lepidoptera
	Pteroma plagiophleps Hmps.	Psychidae	Lepidoptera
Bark-eating caterpillar	*Indarbela theivora* Hmpsn.	Metarbelidae	Lepidoptera
Large bark-eating borer	*I. quadrinotata* Wlk.	Metarbelidae	Lepidoptera
	Belippa lalanea Moore	Limacodiidae	Lepidoptera
White-striped green nettle grub	*Cania bilinea* Wlk.	Limacodiidae	Lepidoptera
Common jelly or gelatine grub	*Cheromettia apicata* Moore	Limacodiidae	Lepidoptera
	Contheyla rotunda H.	Limacodiidae	Lepidoptera
	Darna nararia Moore	Limacodiidae	Lepidoptera
	Latoia lepida (Cramer)	Limacodiidae	Lepidoptera
Small gelatine grub	*Narosa conspersa*	Limacodiidae	Lepidoptera
	Phocederma velutinum Koll.	Limacodiidae	Lepidoptera
Two red spotted green nettle grub	*Praesetoria divergens* Moore	Limacodiidae	Lepidoptera
Humped slug caterpillar	*Spatulicraspeda castaneiceps* Hmpsn.	Limacodiidae	Lepidoptera
	Susica pallida Wlk.	Limacodiidae	Lepidoptera
	Thosea sp. nr. *bisura* Moore	Limacodiidae	Lepidoptera
Saddle-backed nettle grub	*T. cervina* Moore	Limacodiidae	Lepidoptera
Green nettle grub	*T. cana* Wlk.	Limacodiidae	Lepidoptera
	T. crude Wlk.	Limacodiidae	Lepidoptera
	T. cotesi Swinh.	Limacodiidae	Lepidoptera
	T. recta Hmps.	Limacodiidae	Lepidoptera
White-striped yellowish green nettle grub	*T. sinensis* Wlk.	Limacodiidae	Lepidoptera
	Trichogyia nigrimarga Her.	Limacodiidae	Lepidoptera
Purple-striped green nettle grub	*Parasa pastoralis* Bult.	Limacodiidae	Lepidoptera
	Eterusia aedea edocla Doubl.	Zygaenidae	Lepidoptera

	E. aedea virescens Butler	Zygaenidae	Lepidoptera
Red slug caterpillar	*E. magnifica* Bult.	Zygaenidae	Lepidoptera
	E. virescens B.	Zygaenidae	Lepidoptera
	Trypanophora semihyalina Koll.	Zygaenidae	Lepidoptera
	Acroclita sp.	Eucosmidae	Lepidoptera
Flushworm	*Cydia leucostoma* Meyr.	Eucosmidae	Lepidoptera
Tea tortrix	*Homona coffearia* Neitner	Tortricidae	Lepidoptera
Tea leaf webber	*Striglina glareola* Felder	Thyrididae	Lepidoptera
Nest-forming caterpillar	*Syllepte (Sylepta) balteata* Felder	Pyralidae	Lepidoptera
Leaf webber	*Ereboenis saturata* Meyr.	Pyralidae	Lepidoptera
	Estigena pardilis Wlk.	Lasiocampidae	Lepidoptera
	Gastropacha sp.	Lasiocampidae	Lepidoptera
	Taragama sp.	Lasiocampidae	Lepidoptera
	Trabala vishnou Lef.	Lasiocampidae	Lepidoptera
Bunch caterpillar	*Andraca bipunctata* Wlk.	Bombycidae	Lepidoptera
	Cricula trifenestrata H.	Saturniidae	Lepidoptera
	Abraxas sylvata Scop.	Geometridae	Lepidoptera
Common looper	*Buzura (Biston) suppressaria* Guen.	Geometridae	Lepidoptera
	B. bengeliaria Guen.	Geometridae	Lepidoptera
	Boarmla aclenaria Hbn.	Geometridae	Lepidoptera
	B. aciaria Boisd.	Geometridae	Lepidoptera
	Ectropis bhurmitra Walk.	Geometridae	Lepidoptera
	Erebomorpha fulgurita Wlk.	Geometridae	Lepidoptera
	Euschema militaris L	Geometridae	Lepidoptera
	Medasina strixaria Guen.	Geometridae	Lepidoptera
Lobster caterpillar	*Stauropus alternus* (Wlk.)	Notodontidae	Lepidoptera
	Amsacta lactinea Cram.	Arctiidae	Lepidoptera
	A. lineola Fb.	Arctiidae	Lepidoptera
	Pericallia ricini Fb.	Arctiidae	Lepidoptera
Castor semilooper	*Achaea janata* Linn.	Noctuidae	Lepidoptera
	Agrotis ipsilon (Hufn.)	Noctuidae	Lepidoptera
	Spodoptera litura (F.)	Noctuidae	Lepidoptera
	Dasychira thwaitesi Moore	Lymantriidae	Lepidoptera
	D. securis Hbn.	Lymantriidae	Lepidoptera
Tussock caterpillar	*D. horsfieldi* Saund	Lymantriidae	Lepidoptera
	Euproctis divisa Wlk.	Lymantriidae	Lepidoptera
	E. latifascia Wlk.	Lymantriidae	Lepidoptera
Hairy caterpillar	*Olene mendosa* (Hb.)	Lymantriidae	Lepidoptera
	Orgyia postica Wlk.	Lymantriidae	Lepidoptera
	Porthesia scintillans Wlk.	Lymantriidae	Lepidoptera
	Hypsa alciphron Cram.	Hypsidae	Lepidoptera
Tea leaf miner	*Agromyza theae* Meij.	Agromyzidae	Diptera
	Tropicomyia theae (Cotes)	Agromyzidae	Diptera
Sewring blight	*Orasema initiator* Ker.	Eucharitidae	Hymenoptera
	O. assectator Kerrich	Eucharitidae	Hymenoptera
	Crematogaster dohrni Meyr	Formicidae	Hymenoptera

	Technomyrmex detorquens Wlk.	Formicidae	Hymenoptera
	Polyrhachis affinis Sm.	Formicidae	Hymenoptera
	Oecophylla smaragdina (F.)	Formicidae	Hymenoptera
	Xylocopa aestuans Linn.	Apidae	Hymenoptera
White grub	*Holotrichia impressa* Brum.	Melolonthidae	Coleoptera
	H. seticollis Moser.	Melolonthidae	Coleoptera
Leaf-eating cockchafer	*Serica assamensis* Brenske	Melolonthidae	Coleoptera
	Mimela xanthorrhina Hope	Rutelidae	Coleoptera
Root borer	*Batocera rufomaculata* DeG	Cerambycidae	Coleoptera
	Cryptognathus indicus Hope	Cerambycidae	Coleoptera
	Melanauster verteegi Rits	Cerambycidae	Coleoptera
Stem borer	*Hyplothrix griseatus* Gah.	Cerambycidae	Coleoptera
Orange beetle	*Diapromorpha melanopus* Lecord	Chrysomelidae	Coleoptera
Shot-hole borer	*Euwallacea (Xyleborus) fornicatus* E.	Scolytidae	Coleoptera
	Xyleborus semigranosus	Scolytidae	Coleoptera
Large green weevil	*Astycus chrysochlorus* Wield.	Curculionidae	Coleoptera
Small green weevil	*A. lateralis* Fabr.	Curculionidae	Coleoptera

Coffea arabica (COFFEE)

Coffee grasshopper	*Aularches miliaris* D.	Acrididae	Orthoptera
Green leafhopper	*Nophotettix nigropictus* (Stal.)	Cicadellidae	Hemiptera
Coffee whitefly	*Kanakarajiella vulgaris* (Singh)	Aleyrodidae	Hemiptera
Aphid	*Toxoptera aurantii* Boyen.	Aphididae	Hemiptera
	Orthezia insignis D.	Ortheziidae	Hemiptera
Mealy bug	*Dysmicoccus breviceps* (Ckll.)	Pseudococcidae	Hemiptera
Mealy bug	*Planococcus citri* (Riso.)	Pseudococcidae	Hemiptera
Coffee mealy bug	*P. lilacinus* (Ckll.)	Pseudococcidae	Hemiptera
Green bug	*Coccus viridis* (*Gr.*)	Coccidae	Hemiptera
	Pulvinaria psidii M.	Coccidae	Hemiptera
	Saissetia hemisphaerica (Targ)	Coccidae	Hemiptera
	Parasaissetia nigra (Nietn.)	Coccidae	Hemiptera
	Ricania bicolorata D.	Ricariiidae	Hemiptera
Coffee shoot and berry bug	*Antestiopsis cruciata* (F.)	Pentatomidae	Hemiptera
Green plant bug	*Nezara viridula* Linn.	Pentatomidae	Hemiptera
Flower thrips	*Haplothrips ceylonicus* Sch.	Phlaeothripidae	Thysanoptera
Leaf thrips	*Scirtothrips bispinosus* Bagn.	Thripidae	Thysanoptera
Leaf thrips	*Heliothrips haemorrhoidalis* (Bouche)	Thripidae	Thysanoptera
Flower thrips	*Thrips florum* Schmutz	Thripidae	Thysanoptera
	Taeniothrips ditissimus Anan. and Jag.	Thripidae	Thysanoptera
	T. obscurus Anan. and Jag.	Thripidae	Thysanoptera
Red borer	*Zeuzera coffeae* N.	Zeuzeridae	Lepidoptera
Slug caterpillar	*Belippa laleana* M.	Limacodiidae	Lepidoptera
Flush worm	*Homona coffearia* N.	Bombycidae	Lepidoptera
	Eupterote canaraica M.	Bombycidae	Lepidoptera
	E. fabia Cr.	Bombycidae	Lepidoptera

	Tiracola plagiata Walk.	Bombycidae	Lepidoptera
	Agrotis segetum (Schiff)	Noctuidae	Lepidoptera
	Spodoptera litura (F.)	Noctuidae	Lepidoptera
	Olene mendosa Hb.	Lymantriidae	Lepidoptera
Leaf miner	*Acrocercops caerulea* Meyrick	Gracillariidae	Lepidoptera
Coffee leaf miner	*Melanagromyza coffeae* H.	Agromyzidae	Diptera
Root grub	*Holotrichia conferta* S.	Melolonthidae	Coleoptera
	Serica pruinosa B.	Melolonthidae	Coleoptera
Storage beetle	*Alphitobius laevigatus* (Fb.)	Tenebrionidae	Coleoptera
Ground beetle	*Gonocephalum bilineatum* Wlk.	Tenebrionidae	Coleoptera
White borer	*Xylotrechus quadripes* Ch.	Cerambycidae	Coleoptera
Coffee berry beetle	*Araecerus fasciculatus* DeG.	Anthribiidae	Coleoptera
Metallic leaf beetle	*Carinodes sheppardi* B.	Chrysomelidae	Coleoptera
Leaf weevil	*Sympiezomias frater* M.	Curculionidae	Coleoptera
Shot-hole borer	*Xyleborus discolor* Bland.	Scolytidae	Coleoptera
	X. fornicatus E.	Scolytidae	Coleoptera
	Xylosandrus compactus (E.)	Scolytidae	Coleoptera
Coffee berry borer	*Hypothenemus hampei* (Ferrari)	Scolytidae	Coleoptera

Coffea robusta (COFFEE)

	Nephotettix nigropictus (Stal.)	Cicadellidae	Hemiptera
	Toxoptera aurantii Boyer	Aphididae	Hemiptera
	Kanakarajiella vulgaris (Singh)	Aleyrodidae	Hemiptera
Root mealy bug	*Cataenococcus* sp.	Pseudococcidae	Hemiptera
Shoot mealy bug	*Perissopneumon phyllanthi* (Gr.)	Pseudococcidae	Hemiptera
Green bug	*Coccus viridis* (Gr.)	Coccidae	Hemiptera
	Araecerus fasciculatus DeG.	Anthribiidae	Coleoptera
Shoot hole borer	*Xylosandrus compactus* (Eichh.)	Scolytidae	Coleoptera

Theobroma cacao (CACAO)

cotton aphid	*Aphis gossypii* G.	Aphididae	Hemiptera
White-tailed mealybug	*Ferrisia virgata* (Ckll.)	Pseudococcidae	Hemiptera
Mealy bug	*Pseudococcus citri* (Riso)	Pseudococcidae	Hemiptera
	P. lilacinus Ckll.	Pseudococcidae	Hemiptera
	Rastrococcus iceryoides Gr.	Pseudococcidae	Hemiptera
Scale insect	*Saissetia hemisphaerica* (Targ)	Coccidae	Hemiptera
Pod bug	*Helopeltis antonii* S.	Miridae	Hemiptera
Green plant bug	*Nezara viridula* Linn.	Pentatomidae	Hemiptera
Pod borer	*Conogethes punctiferalis* (Guen.)	Pyralidae	Lepidoptera
Slug caterpillar	*Contheyla rotunda*	Limacodiidae	Lepidoptera
caterpillar	*Argina syringa* G.	Hypsidae	Lepidoptera
Pod boring beetle	*Parastasia* sp.	Rutelidae	Coleoptera
Grapevine stem girdler	*Sthenias grisator* Fb.	Cerambycidae	Coleoptera
Stem borer	*Sinoxylon stratum* Lesne	Bostrychidae	Coleoptera
Leaf weevil	*Myllocerus viridanus* F.	Curculionidae	Coleoptera
Shot-hole borer	*Xyleborus discolor* Bland.	Scolytidae	Coleoptera
	Xylosandrus compactus (E.)	Scolytidae	Coleoptera

MEDICINAL PLANTS

Anethum graveolens

Coriander aphid	*Hyadaphis coriandri*	Aphididae	Hemiptera
Butterfly caterpillar	*Papilio machaon*	Papilionidae	Lepidoptera

Atropa belladonna

Cutworm	*Agrotis flammatra*	Noctuidae	Lepidoptera
	A. ipsilon (Hufn.)	Noctuidae	Lepidoptera
Ground beetle	*Gonocephalum* sp.	Tenebrionidae	Coleoptera

Balanites aegyptiaca (HINGOTA)

Pulp feeder	*Ectomyelois caratoniae* Zeller	Pyralidae	Lepidoptera
Seed kernel feeder	*Eupsoropsis* sp.	Noctuidae	Lepidoptera

Cannabis sativa

White ant	*Microtermes obesi* Holmgr.	Termitidae	Isoptera
Mealy bug	*Drosicha mangiferae* (Green)	Margarodidae	Hemiptera
Leaf thrips	*Caliothrips indicus* (B.)	Thripidae	Thysanoptera
Bihar hairy caterpillar	*Spilarctia obliqua* (Wlk.)	Arctiidae	Lepidoptera
Cutworm	*Agrotis ypsilon* Rott.	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
	Ilattia octo (Gn.)	Noctuidae	Lepidoptera
Cutworm	*Mythimna separata* H.	Noctuidae	Lepidoptera
	Spodoptera exigua (Hb.)	Noctuidae	Lepidoptera
	S. litura (F.)	Noctuidae	Lepidoptera
Tussock caterpillar	*Olene mendosa* Hb.	Lymantriidae	Lepidoptera
Stem weevil	*Pempherulus affinis* Fst.	Curculionidae	Coleoptera

Cinchona ledgeriana (CINCHONA)

Mirid bug	*Pachypeltis humeralis* (W.)	Miridae	Hemiptera
Slug caterpillar	*Belippa laleana* M.	Limacodiidae	Lepidoptera
	Popillia chlorion N.	Rutelidae	Coleoptera
Chafer beetle	*Holotrichia repetita* S.	Melolonthidae	Coleoptera
	Rhizotrogus rufus A.	Melolonthidae	Coleoptera
	Serica nilgiriensis S.	Melolonthidae	Coleoptera
Leaf weevil	*Sympiezomias decipiens* M.	Curculionidae	Coleoptera

Derris robusta

Drug store beetle	*Lyctus africanus* Lesne	Lyctidae	Coleoptera

Glycyrrhiza glabra

Drug store beetle	*Lyctus africanus* Lesne	Lyctidae	Coleoptera

Hyoscyamus niger

Plant lice	*Myzus persicae* Sulz.	Aphididae	Hemiptera
Capsule borer	*Helicoverpa armigera* (Hb.)	Noctuidae	Lepidoptera
	H. peltigera S.	Noctuidae	Lepidoptera

Matricaria chamomilla

	Nysius minor Dist.	Lygaeidae	Hemiptera

Mentha arvensis

Leaf caterpillar	*Syngamia abruptalis* Wlk.	Pyralidae	Lepidoptera
	Spilarctia obliqua Wlk.	Arctiidae	Lepidoptera
	Agrotis segetum (Schiff.)	Noctuidae	Lepidoptera
	Autographa chryson Esper.	Noctuidae	Lepidoptera
	A. nigrisigna Wlk.	Noctuidae	Lepidoptera
	Spodoptera exigua (Hb.)	Noctuidae	Lepidoptera
Leaf beetle	*Chrysolina exanthematica* Wield.	Chrysomelidae	Coleoptera

Mucuna pruriens

Aphid	*Aphis craccivora* Koch.	Aphididae	Hemiptera

Ocimum sanctum

Scale insect	*Ceroplastodes cajani* Mask.	Coccidae	Hemiptera
Lace-wing bug	*Monanthia globulifera* Walk.	Tingidae	Hemiptera
Defoliator	*Aethaloessa floridalis* Zeller	Pyralidae	Lepidoptera
Leaf roller	*Pycanarmon caberalis* Guen.	Pyralidae	Lepidoptera
	Syngamia abruptalis Walk.	Pyralidae	Lepidoptera
Leaf caterpillar	*Lyncestis amphix* Cr.	Noctuidae	Lepidoptera

Papaver somniferum (POPPY)

Surface grasshopper	*Chrotogonus* sp.	Acrididae	Orthoptera
Flower thrips	*Frankliniella schultzei* Trybom	Thripidae	Thysanoptera
	Agrotis ipsilon (Hufn.)	Noctuidae	Lepidoptera
	A. segetum (Schiff)	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
	Spodoptera litura (F.)	Noctuidae	Lepidoptera

Polygonum hydropiper (WATER PEPPER)

	Galerucella placida Baly	Galerucidae	Coleoptera

Polygonum serrulatum

	Galerucella placida Baly.	Galerucidae	Coleoptera

Rauwolfia serpentina

	Parotis (=Glyphodes) vertumnalis (Guen.)	Pyralidae	Lepidoptera
Horned caterpillar	*Daphnis nerii* L.	Sphingidae	Lepidoptera

Rumex nepalensis

	Galerucella placida Bably.	Galerucidae	Coleoptera

Tylophora indica

Defoliator	*Hypena quadralis* (Walker)	Noctuidae	Lepidoptera

Winthemia somnifera

Horned caterpillar	*Acherontia styx* West	Sphingidae	Lepidoptera
Spotted leaf beetle	*Epilachna vigintioctopunctata* F.	Coccinellidae	Coleoptera

MASTICATORIES AND FUMATORIES

Areca cathecu (ARECANUT)

Coconut aphid	*Cerataphis brasiliensis* Hrl.	Aphididae	Hemiptera
Areca blackfly	*Aleurocanthus arecae* David and Manjunatha	Aleyrodidae	Hemiptera
	Icerya aegyptiaca (Daugl.)	Margarodidae	Hemiptera
	Chionaspis dilatata G.	Diaspididae	Hemiptera
	Chrysomphalus ficus Ashm.	Diaspididae	Hemiptera
	Pinnaspis aspidistrae S.	Diaspididae	Hemiptera
	P. dracaenae Cooley	Diaspididae	Hemiptera
	Coccus hesperidum L.	Coccidae	Hemiptera
	Dysmicoccus brevipes (Ckll)	Pseudococcidae	Hemiptera
Areca bug	*Carvalhoia arecae* Miller	Miridae	Hemiptera
Leaf thrips	*Rhipiphorothrips cruentatus* H.	Thripidae	Thysanoptera
Flower thrips	*Thrips hawaiiensis* (Morgan)	Thripidae	Thysanoptera
Slug caterpillar	*Contheyla rotunda*	Limacodiidae	Lepidoptera
White grupiu	*Leucopholis lepidophora* BI.	Melolonthidae	Coleoptera
Nut beetle	*Araecerus fasciculatus* DeG	Anthribiidae	Coleoptera
Stored arecanut beetle	*Coccotrypes carpophagus* Horn.	Scolytidae	Coleoptera

Nicotiana tabacum (TOBACCO)

Surface grasshopper	*Atractomorpha crenulata* F.	Acrididae	Orthoptera
	Chrotogonus robertsoni B.	Acrididae	Orthoptera
Plant lice	*Myzus persicae* S.	Aphididae	Hemiptera
Whitefly	*Bemisia tabaci* (Genn.)	Aleyrodidae	Hemiptera
Shoot bug	*Cryptopeltis crassicornis*	Miridae	Hemiptera
Rootbug	*Stibaropus tabulatus* S.	Cydnidae	Hemiptera
Stem borer	*Phthorimoea heliopa* L.	Gelechiidae	Lepidoptera
	P. operculella Z.	Gelechiidae	Lepidoptera
Tobacco seed pest	*Attagenus gloriosa* F.	Pyralidae	Lepidoptera
	Cadra cautella (Wlk.)	Pyralidae	Lepidoptera
Cured tobacco larva	*Nephopteryx eugraphella* Rag.	Pyralidae	Lepidoptera
Wrapper tobacco larva	*Demobrotis* sp.	Pyralidae	Lepidoptera
Dried leaf caterpillar	*Setomorpha tineoides* Wals.	Pyralidae	Lepidoptera
Bihar hairy caterpillar	*Spilarctia obliqua* (Wlk.)	Arctiidae	Lepidoptera

Cutworm	*Agrotis ipsilon* (Hufn.)	Noctuidae	Lepidoptera
	A. spinifera (Hubn.)	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
	H. assulta G.	Noctuidae	Lepidoptera
	Mythimna loreyi (Dupon.)	Noctuidae	Lepidoptera
Green stem borer	*Plusia signata* F.	Noctuidae	Lepidoptera
	Spodoptera exigua Hb.	Noctuidae	Lepidoptera
Tobacco caterpillar	*S. litura* (F.)	Noctuidae	Lepidoptera
Root grub	*Holotrichia serrata* F.	Melolonthidae	Coleoptera
Cigarette beetle	*Lasioderma serricorne* (P).	Anobiidae	Coleoptera
Ground beetle	*Gonocephalum dorsogranosum* F.	Tenebrionidae	Coleoptera
	Mesomorphus villiger Bl.	Tenebrionidae	Coleoptera
	Opatroides frater Farum	Tenebrionidae	Coleoptera
	O. punctulatus Brull.	Tenebrionidae	Coleoptera

Piper betel **(BETELVINE)**

Whiteant	*Odontotermes obesus* Ramb.	Termitidae	Isoptera
	Aleurocanthus rugosa Singh	Aleyrodidae	Hemiptera
Whitefly	*Singhiella pallida* (S.)	Aleyrodidae	Hemiptera
	Aphii gosypii Gl.	Aphididae	Hemiptera
Mealy bug	*Dysmicoccus breviceps* (Ckll.)	Pseudococcidae	Hemiptera
	Ferrisia virgata (Ckll.)	Pseudococcidae	Hemiptera
Root mealy bug	*Geococcus citrinus* Kuwana	Pseudococcidae	Hemiptera
Betelvine scale	*Lepidosaphes cornutus* Ramk.	Diaspididae	Hemiptera
Betelvine bug	*Pachypeltis politus* Dist.	Miridae	Hemiptera
Black bug	*Cyclopelta siccifolia* Westw.	Pentatomidae	Hemiptera

FODDER CROP

Medicago sativa **(LUCERNE)**

	Oxya ebneri Willemse	Acrididae	Orthoptera
	Phaneroptera gracilis Brum.	Acrididae	Orthoptera
	Leptocentrus obliquus Walk.	Membracidae	Hemiptera
	Tricentrus bicolor Dist.	Membracidae	Hemiptera
	Graptostethus servus Fb.	Cicadellidae	Hemiptera
	Aphis craccivora Koch.	Aphididae	Hemiptera
Stem aphid	*Acythosiphon kondoi* Shinji & Kondo	Aphididae	Hemiptera
Leaf aphid	*Therioaphis trifolii* (Monell)	Aphididae	Hemiptera
	Cletus signatus Walk.	Coreidae	Hemiptera
	Antestiopsis cruciata Fb.	Pentatomidae	Hemiptera
	Aspangopus (= Coridius) janus (Fb.)	Pentatomidae	Hemiptera
	Bagrada cruciferarum Kirk.	Pentatomidae	Hemiptera
	Dolycoris indicus Stall.	Pentatomidae	Hemiptera
	Nezara viridula Linn.	Pentatomidae	Hemiptera
	Piezodorus koenigi Fb.	Pyrrhocoridae	Hemiptera

Leaf thrips	*Caliothrips indicus* Bagn.	Thripidae	Thysanoptera
Leaf thrips	*Frankliniella schultzei* Trybom	Thripidae	Thysanoptera
Flower thrips	*Megalurothrips usitatus* (Bagn.)	Thripidae	Thysanoptera
Rice skipper	*Pelopidas mathias* Fb.	Hesperiidae	Lepidoptera
Leaf roller	*Omiodes indicata* F.	Pyralidae	Lepidoptera
	Agrotis spinifer (Hubn.)	Noctuidae	Lepidoptera
	Chrysodeixis erisoma D.	Noctuidae	Lepidoptera
	Helicoverpa armigera (Hb.)	Noctuidae	Lepidoptera
	Mythimna separata (Wlk.)	Noctuidae	Lepidoptera
	Spodoptera exigua (Hb.)	Noctuidae	Lepidoptera
	S. litura (F.)	Noctuidae	Lepidoptera
	Sesamia inferens Wlk	Noctuidae	Lepidoptera
	Spilarctia obliqua (Wlk.)	Arctiidae	Lepidoptera
	Euproctis lunata Wlk.	Lymantriidae	Lepidopera
	E. subnotata Wlk.	Lymantriidae	Lepidoptera
	E. varians (Wlk.)	Lymantriidae	Lepidoptera
	E. virguncula Wlk.	Lymantriidae	Lepidoptera
	Psalis pennatula Fb.	Lymantriidae	Lepidoptera
	Ceratina binghami Ckl.	Apidae	Hymenoptera
Seed chalcid	*Bruchophagous roddi* Guss	Eurytomidae	Hymenoptera
	Aulacophora intermedia Jacoby	Galerucidae	Coleoptera
	Raphidopalpa foveicollis (Lucas)	Galerucidae	Coleoptera
Lucerne weevil	*Hypera postica* (Gyllenhal)	Curculionidae	Coleoptera
	Myllocerus maculosus Desbx.	Curculionidae	Coleoptera

FOREST TREES

Acacia auriculiformis (ACACIA)

Lac insect	*Kerria lacca*	Kerridae	Hemiptera
Castor semilooper	*Achaea janata* Linn.	Noctuidae	Lepidoptera
Cotton bolloworm	*Helicoverpa armigera* (Hb.)	Noctuidae	Lepidoptera
Bagworm	*Eumeta crameri* (Westwood)	Psychidae	Lepidoptera
Stemborer	*Celosterna scabrator* Fb.	Cerambycidae	Coleoptera
Seed borer	*Bruchidius andrewsi*	Bruchidae	Coleoptera
Shot hole borer	*Sinoxylon* sp.	Bostrychidae	Coleoptera
Ash weevil	*Myllocerus viridanus* F.	Curculionidae	Coleoptera

Acacia nilotica

Termite	*Microtermes minor*	Termitidae	Isoptera
Whitefly	*Acaudaleyrodes rachipora* (Singh)	Aleyrodidae	Hemiptera
Bihar hairy caterpillar	*Spilarctia obliqua* (Wlk.)	Arctiidae	Lepidoptera
Hairy caterpillar	*Euproctis lunata* (Wlk.)	Lymantriidae	Lepidoptera
	Trabala vishnou L.	Lasiocampidae	Lepidoptera
Hiary caterpillar	*Selepa celtis* (Moore)	Noctuidae	Lepidoptera
Stem borer	*Celosterna scabrator* Fb.	Cerambycidae	Coleoptera
White grub	*Holotrichia consanguinea* Bl.	Melolonthidae	Coleoptera
Seed beetle	*Caryedon serratus*	Bruchidae	Coleoptera

Ailanthus triphysa (MAHARUKH)

	Aleuroclava mysorensis J. and D.	Aleyrodidae	Hemiptera
	Aleurolobus tuberculatus R. and D.	Aleyrodidae	Hemiptera
	Cockerelliella quaintancei S. and D.	Aleyrodidae	Hemiptera
	Dialeuropora pterolobiae David and Sub.	Aleyrodidae	Hemiptera
Leaf weeber	*Atteva fabriciella* Swed.	Yponomeutidae	Lepidoptera
	A. niveiguttata	Yponomeutidae	Lepidoptera
Atlas moth	*Attacus atlas*	Saurniidae	Lepidoptera
Leaf caterpillar	*Eligma narcissus*	Noctuidae	Lepidoptera

Albizia lebbeck (EAST INDIAN WALNUT)

Termite	*Microtermes minor*	Termitidae	Isoptera
	Eurybrachys tomentosa F.	Eurybrachidae	Hemiptera
Cow bug	*Oxyrachis tarandus* Fb.	Membracidae	Hemiptera
Shoot spittle bug	*Ptyelinellus praefractus*	Cercopidae	Hemiptera
Lacwing bug	*Tingis beesoni*	Tingidae	Hemiptera
Bark borer	*Indarbela quadrinotata* W.	Metarbelidae	Lepidoptera
	Stathmopoda basiplectra	Heliodinidae	Lepidoptera
Leaf webber	*Pyrausta ochracealis*	Pyralidae	Lepidoptera
Leaf miner	*Phyllocnistis amydropa*	Gracillariidae	Lepidoptera
Buterfly	*Eurema blanda silhetana* Wallace	Pieridae	Lepidoptera
Cutworm	*Agrotis ypsilon* (Rott.)	Noctuidae	Lepidoptera
Defoliator	*Pericyma glaucinans*	Noctuidae	Lepidoptera
Foliage feeder	*Spirama retorta* Cram.	Noctuidae	Lepidoptera
Looper caterpillar	*Semiothisa pluviata*	Geometridae	Lepidoptera
Leaf webber	*Epilema fulvilinea*	Epiplemidae	Lepidoptera
	Diacrotrichia leucomochila	Pterophoridae	Lepidoptera
Stem borer	*Acalolepta rusticatrix* Fb.	Ceramybycidae	Coleoptera
Bark borer	*Derolus volvulus*	Cerambycidae	Coleoptera
	Dihammus cervinus	Cerambycidae	Lepidoptera
Bark borer	*Xystrocera globosa Oliv.*	Ceramybycidae	Coleoptera
	Phloebius pilipes	Anthribiidae	Coleoptera
	Tropideres bolinus	Anthribiidae	Coleoptera
	T. luteago	Anthribiidae	Coleoptera
	T. notabilis	Anthribiidae	Coleoptera
Seed beetle	*Bruchidius sparsemacuatus* (P.)	Bruchidae	Coleoptera
Shot hole borer	*Euwallacea fornicatus* (E.)	Scolytidae	Coleoptera
	Alcidodes gmelinae	Curculionidae	Coleoptera
	Calopepla laeyana	Chrysomelidae	Coleoptera

Albizia odoratissima

Psyllid bug	*Psylla oblonga*	Psyllidae	Hemiptera
Cow bug	*Oxyrachis tarandus* Fb.	Membracidae	Hemiptera
Leaf feeder	*Archips* sp.	Tortricidae	Lepidoptera

Nursery leaf caterpillar	*Rhesala moestalis* (Wlk.)	Tortricidae	Lepidoptera
Seed borer	*Callasobruchus chinensis*	Bruchidae	Lepidoptera
Seed borer	*Caryedon serratus* Oliv.	Bruchidae	Lepidoptera

Alstonia scholaris

Defoliator	*Parotis vertumnalis* (Guenee)	Pyralidae	Lepidoptera

Azadirachta indica (NEEM)

Wingless grasshopper	*Neorthacris simulans*	Acrididae	Orthoptera
Flower and leaf thrips	*Taeniothrips chaetogastra* Ramk.	Thripidae	Thysanoptera
Leaf thrips	*Dolichothrips indicus* (Hood)	Phlaeothripidae	Thysanoptera
Tea mosquito bug	*Helopeltis antonii* S.	Miridae	Hemiptera
	Dialeurodes armatus David and Sub.	Aleyrodidae	Hemiptera
Mealy scale	*Pulvinaria maxima* Green	Pseudococcidae	Hemiptera
Leaf webber	*Laspeyresia aurantiana*	Eucosmidae	Lepidoptera
Slug caterpillar	*Latoia lepida* C.	Limacodiidae	Lepidoptera
Leaf beetle	*Cryptocephalus ovulum*	Ceyptocephalidae	Coleoptera
Defoliator	*Anomala* sp.	Ruteliidae	Coleoptera
	Holotrichia serrata (Fabr.)	Melolonthidae	Coleoptera
Seed borer	*Araecerus fasciculatus De* Geer	Anthribiidae	Coleoptera
Seed kernel borer	*Oryzaephilus surinamensis* Linn.	Cucujidae	Coleoptera

Bambusa spp. (BAMBOO) (Living)

Thrips	*Podothrips bambusae* Seshadri and Ananth.	Phlaeothripidae	Thysanoptera
	Praepodothrips priesneri Ananthakrishnan	Phlaeothripidae	Thysanoptera
Thrips	*Thrips bambusae* Shumster	Thripidae	Thysanoptera
Thrips	*Veerabahuthrips bambusae* Ramakrishna	Phlaeothripidae	Thysanoptera
Thrips	*Xylaplothrips nayari* Ananthakrishnan	Phlaeothripidae	Thysanoptera
Bamboo aphid	*Oregma bambusae* Buckton	Aphididae	Hemiptera
	Aleurocanthus bambusae Peal	Aleyrodidae	Hemiptera
	A. longispinus Q. and B.	Aleyrodidae	Hemiptera
	A. seshadrii David and Sub.	Aleyrodidae	Hemiptera
	Aleurotrachelus multipapillus Singh	Aleyrodidae	Hemiptera
	Aleurotulus arundinacea Singh	Aleyrodidae	Hemiptera
	Tetraleurodes bambusae J. and D.	Aleyrodidae	Hemiptera
Plant bug	*Udonga montana* Distant	Pentatomidae	Hemiptera
	Algedonia bambucivora	Pyralidae	Lepidoptera

BAMBOO (Stored)

Tiger longicorn beetle	*Chlorophorus annularis* Fabricius	Cerambycidae	Coleoptera
Powder post beetle	*Lyctus africanus* Lesne	Lyctidae	Coleoptera

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Shot hold borer	*Dinoderus japonicus* Lesne	Bostrychidae	Coleoptera
Ghoon borer	*D. minutus* Fabricius	Bostrychidae	Coleoptera

Bombax malabarica

Looper caterpillar	*Thalassodes opalina* Butler	Geometridae	Lepidoptera
Hairy caterpillar	*Euproctis fraterna* (Moore)	Lymantriidae	Lepidoptera
Defoliator	*Indomias cretaceus*	Curculionidae	Coleoptera
Defoliator	*I. hispidus* (Marshall)	Curculionidae	Coleoptera
Stem borer	*Glenea homonospila* Thom.	Cerambycidae	Coleoptera

Bridelia squamosa

Leaf roller	*Apoderus scitulus* Wlk.	Curculionidae	Coleoptera

Careya arborea

Leaf caterpillar	*Aeolonthes dicraea* (Meyrick)	Oecophoridae	Lepidoptera
Leaf feeder	*Limnoecia* sp. nr. *peronodus* Meyrick	Cosmopterygidae	Lepidoptera
Sap feeder	*Tettigoniella indistincta* Wlk.	Cicadellidae	Hemiptera
Cow bug	*Centrotypus* sp.	Membracidae	Hempitera
Fruit borer	*Teluropus ballardi* Marshall	Curculionidae	Coleoptera
Fruitfly	*Bactrocera* sp. nr. *tuberculatus* (Bezzi)	Tephritidae	Diptera

Cassia auriculata

Pod borer	*Argyroploce illepida*	Eucosmidae	Lepidoptera
Leaf webber	*Pilocrocis milvinalis*	Pyralidae	Lepidoptera
Looper caterpillar	*Biston suppressaria*	Geometridae	Lepidoptera
Defoliator	*Fodina stola*	Noctuidae	Lepidoptera
Pierid butterfly	*Catopsilia crocale*	Pieridae	Lepidoptera
	C. pomona (Fabricius)	Pieridae	Lepidoptera
	C. pyranthe (Linnaeus)	Pieridae	Lepidoptera
Stem borer	*Aristobia approximator*	Cerambycidae	Coleoptera
	A. octofasciculata	Cerambycidae	Coleoptera
	A. testudo	Cerambycidae	Coleoptera
Defoliator	*Anomala bengalensis* Bl.	Rutelidae	Coleoptera
	A. politta	Coleoptera	*Cassia* fistula

Cassia fistula

Defoliator	*Catopsilia pyranthe* Herbst.	Pieridae	Lepidoptera
Leaf webber	*Deba surrectalis* Wlk.	Pyralidae	Lepidoptera
Pod borer	*Trachylepidia frueticassiella* Ragonot	Galleriidae	Lepidoptera
Leaf feeder	*Maladera* sp.	Melolonthidae	Coleoptera

Cassia siamea

Spiralling whitefly	*Aleurodicus dispersus* Russell	Aleyrodidae	Hemiptera
Stem borer	*Celosterna scabrator* Fb.	Cerambycidae	Coleoptera

Casuarina equisetifolia (CASUARINA)

Leaf cutting cricket	*Brachytrypes portentosus* Lich.	Gryllidae	Orthoptera
Leaf cutting cricket	*Gymnogryllus erythrocephalus Serville*	Gryllidae	Orthoptera
Leaf cutting cricket	*G. humeralis* Walker	Gryllidae	Orthoptera
Wood boring termites	*Neotermes greeni* Desneux	Termitidae	Isoptera
Subterranean termite	*Odontotermes obesus* Rambur	Termitidae	Isoptera
Subterranean termite	*O. walloensis* Wasmann	Termitidae	Isoptera
Wood boring termites	*Postelectrotermes militaris* Desneux	Termitidae	Isoptera
Sap feeder	*Coccus elongatus* Signoret	Coccidae	Hemiptera
Scale insect	*Naiacoccus serpentinus* Green	Coccidae	Hemiptera
Fluted scale insect	*Icerya aegyptiaca* Douglas	Margarodidae	Hemiptera
Lantana bug	*Orthezia insignis* B.	Ortheziidae	Hemiptera
Tasar silkworm	*Antheraea paphia*	Saturniidae	Lepidoptera
Needle miner	*Eumenodora tetrachorda* Meyrick	Cosmopterygidae	Lepidoptera
Needle miner	*Labdia xylinaula* Meyrick	Cosmopterygidae	Lepidoptera
Needle miner	*Metharmostis asaphaula* Moore	Lithocolletidae	Lepidoptera
Leaf feeder	*Maruca testulalis*	Pyralidae	Lepidoptera
Needle borer	*Metharmostis asaphaula*	Gracillariidae	Lepidoptera
Bagworm	*Eumeta crameri* (Westwood)	Psychidae	Lepidoptera
Bagworm	*Eumeta variegata* Snellen	Psychidae	Lepidoptera
Stem girdler	*Melasina campestris*	Tineidae	Lepidoptera
	M. energa Meyrick	Tineidae	Lepidoptera
Sapling borer	*Sahyadrassus malabaricus* Moore	Hepialidae	Lepidoptera
Coffee borer	*Zeuzera coffeae* Nietner	Zeuzeridae	Lepidoptera
Bark caterpillar	*Indarbela quadrinotata* Walker	Metarbelidae	Lepidoptera
Bark caterpillar	*I. tetraonis* Moore	Metarbelidae	Lepidoptera
Hairy caterpillar	*Lymantria detersa* Walker	Lymantriidae	Lepidoptera
Leaf caterpillars	*Spodoptera litura* Fb.	Noctuidae	Lepidoptera
Cutworm	*S. mauritia* Boisduval	Noctuidae	Lepidoptera
Stem borer	*Celosterna scarbrator* Fb.	Cerambycidae	Coleoptera
Defoliator	*Hamartus instabilis* Marshall	Curculionidae	Coleoptera
Seed borer	*Caryedon gonagra* Fb.	Bruchidae	Coleoptera
See wasp	*Bootanomyia orientalis* Mathur and Hussey	Torymidae	Hymenoptera

Cedrus deodara (CEDAR)

Cicadid	*Paharia casyapae*	Cicadidae	Hemiptera
	Dioryceria abietella	Pyralidae	Lepidoptera
	Euzophera cedrella	Pyralidae	Lepidoptera
Cedar shoot borer	*Hypsipyla robusta*	Pyralidae	Lepidoptera
Defoliator	*Ectropis deodorae*	Geometridae	Lepidoptera
Greasy cut worm	*Agrotis ipsilon*	Noctuidae	Lepidoptera
Cut worm	*Euxoa segetis*	Noctuidae	Lepidoptera
	E. spinifera	Noctuidae	Lepidoptera
Bark beetle	*Hylobius angustus*	Curculionidae	Coleoptera

	Lophosternus hugelii	Cerambycidae	Coleoptera
Stem borer	*Ips longifolia*	Scolytidae	Coleoptera
	Pityogenes scitus	Scolytidae	Coleoptera
	Polygraphus major	Scolytidae	Coleoptera
Shot hole borer	*Scolytus major*	Scolytidae	Coleoptera
Wood borer	*Buprestis geometrica*	Buprestidae	Coleoptera
	B. kasmirensis	Buprestidae	Coleoptera
Sap wood borer	*Sphenoptera aterrima*	Buprestidae	Coleoptera
	S. besesoniama	Buprestidae	Coleoptera
	S. konbirensis	Buprestidae	Coleoptera
	S. lafertei	Buprestidae	Coleoptera
	Periobium luteopilosum	Anobiidae	Coleoptera
	Cistelomorpha andrewesi	Chrysomelidae	Coleoptera
	C. annuligera	Chrysomelidae	Coleoptera

Dalbergia sissoo Roxb. (SHISHAM)

	Acaudaleyrodes rachipora (Singh)	Aleyrodidae	Hemiptera
	Aleurolobus cassiae J. and D.	Aleyrodidae	Hemiptera
	A. niloticus Pr. and H.	Aleyrodidae	Hemiptera
	Aleurotrachelus tuberculatus Singh	Aleyrodidae	Hemiptera
	Dialeuropora decempuncta (Q. and B.)	Aleyrodidae	Hemiptera
Mealy bug	*Nipaecoccus vastator* (Mask.)	Pseudococcidae	Hemiptera
	Dichomeris eridantis Meyr.	Gelechiidae	Lepidoptera
	Plecoptera reflexa	Noctuidae	Lepidoptera
Semilooper	*Thysanoplusia orichalcea* (F.)	Noctuidae	Lepidoptera
Leaf miner	*Leucoptera sphenograpta* Meyr.	Lyonetiidae	Lepidoptera
	Neptis jumbah	Nymphalidae	Lepidoptera
	Enarmonia jaculatrix	Eucosmidae	Lepidoptera
Shot hole borer	*Sinoxylon anale*	Bostrychidae	Coleoptera
	Thea bisoctonotata	Coccinellidae	Coleoptera
	T. incta	Coccinellidae	Coleoptera
Bark feeder	*Aristobia horridula* Hope	Cerambycidae	Coleoptera
Flat headed borer	*Acamaeodera kerremansi*	Buprestidae	Coleoptera
Borer	*Anthaxia marshalli*	Buprestidae	Coleoptera
Twig borer	*Ernoporus concentralis*	Scolytidae	Coleoptera
Leaf roller	*Apoderus blandus*	Curculionidae	Coleoptera
	A. sussu	Curculionidae	Coleoptera

Dalbergia paniculata

Seed borer	*Sulcobruchus kingsolsveri* Arora	Bruchidae	Coleoptera

Eucalyptus spp.

Termite	*Odontotermes* sp.	Termitidae	Isoptera
Termite	*Microtermes* sp.	Termitidae	Isoptera
Spiralling whitefly	*Aleurodicus dispersus* Russell	Aleyrodidae	Hemiptera
Thrips	*Retithrips syriacus* (Mayet)	Thripidae	Thysanoptera

Termite	*Odontotermes* sp.	Termitidae	Isoptera
Stem borer	*Sahayadrassus malabaricus* Moore	Hepialidae	Lepidoptera
Hairy caterpillar	*Trabala vishnou* L.	Lasiocampidae	Lepidoptera
Bagworm	*Pteroma plagiophleps* Hmpsn.	Psychidae	Lepidoptera
Stem borer	*Celosterna scabrator* Fb.	Cerambycidae	Lepidoptera

Garuga pinnata

Sap feeder	*Drabescus* sp.	Cicadellidae	Hemiptere
Plant bug	*Coptosoma variegata* (h.)	Plataspididae	Hemiptera
Gall psyllid	*Phacopteron lentiginosum* Buckton	Psyllidae	Hemiptera
Foliage feeder	*Assara albisostalis* Wlk.	Phycitidae	Lepidoptera
Foliage feeder	*Macalla nubilalis* Hamp.	Phycitidae	Lepidoptera
Foliage caterpillar	*Earias flavida sulphuraria* Moore	Noctuidae	Lepidoptera
Leaf folder	*Adoxophyes moderanata* Wlk.	Tortricidae	Lepidoptera
Leaf beetle	*Adoretus coronatus* Burm.	Scarabaeidae	Coleoptera
Leaf beetle	*Apophylea sericea* Fb.	Chrysomelidae	Coleoptera
Leaf beetle	*Ophrida marmoria* Wield.	Chrysomelidae	Coleoptera
Leaf feeder	*Campsosternus* sp.	Elateridae	Coleoptera

***Gmelina arborea* (GAMHAR)**

Tingid bug	*Tingis beesoni*	Tingidae	Hemiptera
Shoot spittle bug	*Ptyelinellus praefractus*	Cercopidae	Hemiptera
	Aleuropapillatus gmelinae David *et al.*	Aleyrodidae	Hemiptera
Leaf feeder	*Diacrotricha leucomochla* Fletcher	Pterophoridae	Lepidoptera
Leaf webber	*Pyrausta ochracealis* Walker	Pyralidae	Lepidoptera
Leaf miner	*Phyllocnistis amydropa*	Gracillariidae	Lepidoptera
Hairy caterpillar	*Trabal vishnou* L.	Lasiocampidae	Lepidoptera
Leaf beetle	*Calopepla leyana*	Chrysomelidae	Coleoptera
Stem borer	*Acalolepta rusticatrix*	Cerambycidae	Coleoptera
	Dihammus cervinus	Cerambycidae	Coleoptera
Shot hole borer	*Euwallacea fornicatus* (E.)	Scolytidae	Coleoptera
Bark borer	*Phloebius pillipes*	Anthribiidae	Coleoptera
Shoot weevil	*Alcidodes gmelinae*	Curculionidae	Coleoptera
Leaf feeder	*Epilema fulvilinea*	Eupelmidae	Coleoptera
	Calopepla laeyana	Chrysomelidae	Coleoptera

Grewia tiliaefolia

Leaf caterpillar	*Lygropia orbinusalis* Wlk.	Pyralidae	Lepidoptera
Leaf folder	*L. quaternalis* Zeller	Pyralidae	Lepidoptera
Leaf webber	*Archips* sp.	Tortricidae	Lepidoptera
Defoliator	*Hyposidra talaca* Wlk.	Geometridae	Lepidoptera
	Anomis figlina	Noctuidae	Lepidoptera
	Symitha nolatella Wlk.	Noctuidae	Lepidoptera
Leaf weevil	*Henicolabus octomaculatus* Tek.	Curculionidae	Coleoptera
Leaf weevil	*Indomias hispidus* (Marshall)	Curculionidae	Coleoptera
Leaf weevil	*Nisathra medurensis* Jac.	Curculionidae	Coleoptera

Haldina cordifolia

Defoliator	*Epipelma quadricaudata*	Epipelmidae	Lepidoptera
Leaf roller	*Parotis vertumnalis* (Guenee)	Pyralidae	Lepidoptera

Lagerstroemia cordifolia

Leaf caterpillar	*Symitha nolataella* Wlk.	Noctuidae	Lepidoptera
Leaf beetle	*Deracetina brettinghami* Baly	Galeuricidae	Coleoptera
Leaf beetle	*D. collina* (Weise)	Galeuricidae	Coleoptera
Leaf beetle	*Monolepta longitarsis* (Jacoby)	Galeuricidae	Coleoptera
Leaf beetle	*Diapromorpha turcica* (Fb.)	Chrysomelidae	Coleoptera
Leaf beetle	*Cryptocephalus sexisignatus* Fb.	Cryptocephalidae	Coleoptera
Weevil	*Indomias cretaceus* (Faust)	Curculionidae	Coleoptera

Leucaena leucophalea (SUBABUL)

Psyllid bug	*Heteropsylla cubana* Crawford	Psyllidae	Hemiptera
Whitefly	*Bemisia leakii* Peal	Aleyrodidae	Hemiptera

Paraserianthes falcataria (ALBIZIA)

Stem borer	*Sahyadrassus malabaricus*	Hepialidae	Lepidoptera
Bark caterpillar	*Indarbela quadrinotata* W.	Indarbelidae	Lepidoptera
Bagworm	*Pteroma plagiophleps* Hmpsn.	Psychidae	Lepidoptera
Yellow butterfly	*Eurema blanda silhetana* Wallace	Pieridae	Lepidoptera
Yellow butterfly	*E. hecabe contubernalis* Moore	Pieridae	Lepidoptera

Pinus sp. (TROPICAL PINE)

	Dioryctria castanea	Pyralidae	Lepidoptera
	Tomicus khasianus	Scolytidae	Lepidoptera

Populus deltoides (POPLAR)

Poplar leaf webber	*Asphadastis cryphomycha* Meyr.		Lepidoptera
Poplar defoliator	*Clostera cupreata* Butler	Notodontidae	Lepidoptera
	C. fulgaritta Walker	Notodontidae	Lepidoptera

Pterocarpus marsupium

Leaf vein gall	*Arytaina* sp.	Psyllidae	Hemiptera
Foliage pouch gall	*Padaukia kino* Hollis and Martin	Psyllidae	Hemiptera
Gall psyllid	*Spanioneura* sp.	Psyllidae	Hemiptera
Seed borer	*Eucosma* sp.	Eucosmidae	Lepidoptera
Leaf beetle	*Aetheomorpha malayana* (Baly)	Chrysomelidae	Coleoptera
Tender leaf beetle	*Sphenoptera indica* Lap. and Gory.	Buprestidae	Coleoptera
Leaf weevil	*Indomias hispidus* (Marshall)	Curculionidae	Coleoptera

Santalum album (SANDAL)

	Letana inflata	Tettigoniidae	Orthoptera
Leaf folder	*Crotonorthrips davidi* Ananthakrishnan	Thripidae	Thysanoptera

Gall thrips	*Mesothrips manii* Anan	Phlaeothripidae	Thysanoptera
	Eurybrachys tomentosa Fab.	Eurybrachidae	Hemiptera
Cow bug	*Otinotus oneratus*	Membracidae	Hemiptera
Spiralling whitefly	*Aleurodicus dispersus* Russell	Aleyrodidae	Hemiptera
Sandal tree issid	*Sarima nigrohypeata*	Issidae	Hemiptera
Sandal tree jassid	*Jassus indicus*	Cicadellidae	Hemiptera
	Inglisia bivalvata Green	Coccidae	Hemiptera
Hairy caterpillar	*Amata passalis* (Fabricius)	Arctiidae	Lepidoptera
Borer	*Zeuzera coffeae*	Zeuzeridae	Lepidoptera
Leaf roller	*Cocoecia micacaeana*	Tortricidae	Lepidoptera
	Sinoxylon atratum	Bostrychidae	Coleoptera
Defoliator	*Dicronychus lacertosus*	Elateridae	Coleoptera
Ant-like beetle	*Fomicomus caeruleipennis*	Anthicidae	Coleoptera
	F. maindroni	Anthicidae	Coleoptera
	F. sulcipes	Anthicidae	Coleoptera
Flower beetle	*Mylabris macilenta*	Meloidae	Coleoptra
	M. pustulata Th.	Meloidae	Coleoptera

Shorea robusta (SAL)

Hairy caterpillar	*Trabala vishnou* L.	Lasiocampidae	Lepidoptera
White grub	*Holotrichia consanguinea* Blanch	Melolonthidae	Coleoptera
Sal heartwood borer	*Hoplocerambyx spinicornis*	Cerambycidae	Coleoptera

Shorea roxburghii

Grasshopper	*Chrotogonus* sp.	Acrididae	Orthoptera
	Oxya nitidula Willemse	Acrididae	Orthoptera
Lac insect	*Kerria lacca* (Kerr)	Kerridae	Hemiptera
	Getrontha captiosella	Tineidae	Lepidoptera
Seed borer	*Parmmene theristis*	Eucosmidae	Lepidoptera
Defoliator	*Ingura subapicalis*	Noctuidae	Lepidoptera
	Selepa celtis M.	Noctuidae	Lepidoptera
Defoliator	*Ascotis imparata*	Geometridae	Lepidoptera
	A. infixaria	Geometridae	Lepidoptera
Brown loopers	*Hyposidra successaria* Wlk.	Geometridae	Lepidoptera
	H. talaca	Geometridae	Lepidoptera
Defoliator	*Trypamophora semihyaline*	Zygaenidae	Lepidoptera
Hairy caterpillar	*Metanastria hyrtaca*	Lasiocampidae	Lepidoptera
	Suana concolor	Lasiocampidae	Lepidoptera
	Trabala vishnou L.	Lasiocampidae	Lepidoptera
Hairy caterpillars	*Lymantria ampla*	Lymantriidae	Lepidoptera
	L. bivittata	Lymantriidae	Lepidoptera
	L. mathura	Lymantriidae	Lepidoptera
	L. semicincta	Lymantriidae	Lepidoptera
	L. serva	Lymantriidae	Lepidoptera
	L. suburosea	Lymantriidae	Lepidoptera
	L. todara	Lymantriidae	Lepidoptera

Mango stem borer	*Batocera rufomaculata* DeG.	Cerambycidae	Coleoptera
Acacia borer	*Celosterna scabrator* Fb.	Cerambycidae	Coleoptera
Sal borer	*Haplocerambyx spinicornis*	Cerambycidae	Coleoptera
	Xylotrechus bugueti	Cerambycidae	Coleoptera
	X. smei	Cerambycidae	Coleoptera
Defoliators	*Adoretus coliginosus*	Melolonthidae	Coleoptera
Defoliators	*Holotrichia consanguinea* Bl.	Melolonthidae	Coleoptera
	H. problematica	Melolonthidae	Coleoptera
	Allaeometrus breviceps	Brenthidae	Coleoptera
	Microtrachelizus beneficus	Brenthidae	Coleoptera
Wood borers	*Chrysobothris andamana*	Buprestidae	Coleoptera
	C. bicolor	Buprestidae	Coleoptera
	C. beesoni	Buprestidae	Coleoptera
	C. gardneri	Buprestidae	Coleoptera
	C. gratiosa	Buprestidae	Coleoptera
	C. indica	Buprestidae	Coleoptera
	C. opulanta	Buprestidae	Coleoptera
	C. sexnotata	Buprestidae	Coleoptera
	Dereodus pollinosus	Curculionidae	Coleoptera
	Myllocerus sabulorus	Curculionidae	Coleoptera
	M. severini	Curculionidae	Coleoptera
	Sweitenia macrophylla **(MAHOGANY)**		
Looper caterpillar	*Hemithea tritonaria* Walker	Geometridae	Lepidoptera
Shoot borer	*Hypsipyla robusta* Wlk.	Pyralidae	Lepidoptera
Coffeestem borer	*Zeuzera coffeae* N.	Zeuzeridae	Lepidoptera
	Tectona grandis **(TEAK)**		
Spotted locust	*Aularches miliaris* D.	Acrididae	Orthoptera
Tingid bug	*Pontanus puerilis* Drake and Poor	Tingidae	Hemiptera
Cotton aphid	*Aphis gossypii* K.	Aphididae	Hemiptera
Spiralling whitefly	*Aleurodicus dispersus* Russell	Aleyrodidae	Hemiptera
	Aleurolobus sundararaji Regu and David	Aleyrodidae	Hemiptera
	Taiwanaleyrodes fletcheri Jes. and David	Aleyrodidae	Hemiptera
Mealy bug	*Maconellicoccus hirsutus* (Green)	Pseudococcidae	Hemiptera
Cow bug	*Otinotus oneratus*	Membracidae	Hemiptera
	Ricania speculum (Wlk.)	Ricanidae	Hempitera
Teak defoliator	*Hyblaea puera* Cramer	Hyblaeidae	Lepidoptera
Leaf miner	*Labdia callistrepta*	Cosmopterygidae	Lepidoptera
Teak skeletonizer	*Eutectona machearalis* (Walker)	Pyralidae	Lepidoptera
Leaf folder	*Vertumnalis*	Pyralidae	Lepidoptera
	Syllepte (= Sylepta) straminea	Pyralidae	Lepidoptera
Looper caterpillar	*Ectropis bhurmitra*	Geometridae	Lepidoptera
Looper caterpillar	*Hyposidra robusta*	Geometridae	Lepidoptera

Looper caterpillar	*H. sucessaria*	Geometridae	Lepidoptera
Looper caerpillar	*H. talaca*	Geometridae	Lepidoptera
Leaf caterpillar	*Spodoptera litura* F.	Noctuidae	Lepidoptera
Black hairy caterpillar	*Estigmene lactinea*	Arctiidae	Lepidoptera
Leaf hairy caterpillar	*Spilarctia obliqua* (Wlk.)	Arctiidae	Lepidoptera
Hairy caterpillar	*Euproctis fraterna* M.	Lymantriidae	Lepidoptera
Hairy caterpillar	*Dasyehira grotei*	Lymantriidae	Lepidoptera
Hairy caterpillar	*D. mendosa* Hb.	Lymantriidae	Lepidoptera
	Euproctis fraterna	Lymantriidae	Lepidoptera
Death's head moth	*Acherontia styx* W.	Sphingidae	Lepidoptera
Humming bird hawk moth	*Cephonodas ficus*	Sphingidae	Lepidoptera
Humming bird hawk moth	*C. hylas*	Sphingidae	Lepidoptera
Bark caterpillar	*Indarbela tetraonis* Moore	Metarbelidae	Lepidoptera
Bark caterpillar	*I. quadrinotata* W.	Metarbelidae	Lepidoptera
Stem borer	*Alcterogystia cadambae* Moore	Cossidae	Lepidoptera
Stem borer	*Sahyadrassus malabaricus*	Hepialidae	Lepidoptera
Gall midge	*Asphondylia tectonae* Mani	Cecidomyiidae	Diptera
Stem borer	*Celosterna scabrator* Fab.	Cerambycidae	Coleoptera
	Clytus minutus	Cerambycidae	Coleoptera
	Dihamus cervinus	Cerambycidae	Coleoptera
	D. elongatus	Cerambycidae	Coleoptera
	D. punctifrons	Cerambycidae	Coleoptera
Sap wood borer	*Glenea indiana*	Cerambycidae	Coleoptera
Coffee wihte borer	*Xylotrechus quadripes* (Chevr.)	Cerambycidae	Coleoptera
White grub	*Holotrichia* sp.	Melolonthiadae	Coleoptera
	Psiloptera fastuosa	Buprestidae	Coleoptera
Leaf beetle	*Alcidodes ludifactor*	Curculionidae	Coleoptera
	Episomus lacerta	Curculionidae	Coleoptera
	Sympiezomias beesoni	Curculionidae	Coleoptera
Leaf beetle	*Colasposoma asperatum*	Galeuricidae	Coleoptera
Leaf beetle	*C. downsei*	Galeuricidae	Coleoptera
Leaf beetle	*C. metallicum*	Galeuricidae	Coleoptera
Leaf beetle	*C. semicostatum*	Galeuricidae	Coleoptera
Root feeder	*Clinteria klugi*	Cetoniidae	Coleoptera

Toona ciliata (TOONA)

Defoliator	*Hypsipyla rubusta* Wlk.	Pyralidae	Lepidoptera
Hairy caterpillar	*Creatonotus transiens*	Arctiidae	Lepidoptera
Collar-borer	*Pagiophloeus longiclavis*	Curculionidae	Coleoptera

Xylia xylocarpa

	Agrotera basinotata Hamp.	Pyralidae	Lepidoptera
Leaf webber	*Maruca testulalis* Geyer	Pyralidae	Lepidoptera
Shoot borer	*Phycita* sp. nr. *obliquifaciella*	Phycitidae	Lepidoptera
Leaf feeder	*Xyroptila tectonica* Meyr.	Pterophoridae	Lepidoptera
Bark caterpillar	*Indarbela tetraonis* Moore	Metarbelidae	Lepidoptera

Looper caterpillar	*Oenospila quadraria* Wlk.	Geometridae	Lepidoptera
Looper caterpillar	*Sauris* sp. nr. *cinerosa* W.	Geometridae	Lepidoptera
Leaf webber	*Rhodoneura* sp. nr. *myrtacea* Drury	Thyrididae	Lepidoptera
Butterfly	*Azanus* sp.	Lycaenidae	Lepidoptera
Leaf caterpillar	*Curetis* sp.	Lycaenidae	Lepidoptera
Leaf weevil	*Apoderus gracilis* Voss.	Curculionidae	Coleoptera
Leaf weevil	*A. scitulus* Wlk.	Curculionidae	Coleoptera
Leaf weevil	*Eugnathus curvus* Faust	Curculionidae	Coleoptera
Leaf weevil	*Indomias hispidus* Marshall	Curculionidae	Coleoptera
Leaf perforator	*Hoplasoma unicolor* (Illiger)	Chrysomelidae	Coleoptera
Seed borer	*Caryedon serratus*	Bruchidae	Coleoptera

References

Abdulla Koya, K.M., S. Devasahayam and T. Prem Kumar, (1991. Insect Pests of ginger (*Zingiber officinale*) and Turmeric (*Curcuma longa*) in India. *J. Plantation Crops* **19:** 1-13.

Abubucker, A. H., 1966. Studies on the bionomics of *Notolophus posticus,* a pest on castor in Madras State. *Madras Agric. J.*, **53**: 499-505.

Adams, T.S., 1970. Ovarian regulations of the corpus allatum in the housefly *Musca domestica. J. Insect Physiol.,* **16**: 369-81.

Agarwal, N. S. and N. D. Pandey, 1961. Bionomics of *Melanagromyza phaseoli* Coq. (Diptera: Agromyzidae). *Indian J. entomol.,* **23**: 293-98.

Ahmad, T., 1938. The Tur podfly, *Agromyza obtusa* Mall., a pest of *Cajanus cajan. Indian J. Agric Sci.*, **8:** 63-76.

Ahmad, T. and R. L. Gupta, 1941. The pea leaf-miner *Phytomyza atricornis* (Meigen) in India. *Indian J. entomol.,* **3**: 7-49.

Ahuja, D.B. and D.R.C. Bakhetia, 1995. Bioecology and management of insect pests of Sesame–A Review. *J. Insect Sci.*, **8**: 1-19.

Alexander Jesudasan, R.W. and B.V. David, 1991. *Taxonomic Studies on Indian Aleyrodidae* (Insecta: Homoptera). *Oriental Insects*, **25**: 231-434.

Anand Prakash and Jagadiswari Rao (Eds.), 1997. *Botanical Pesticides in Agriculture.* CRC Press Inc., U.S.A., p 461.

Ananthakrishnan, T. N., 1969. *Indian Thysanoptera.* CSIR Zool. Monograph 1, p 171.

Ananthakrishnan, T. N., 1971. Thrips in Agriculture, Horticulture and Forestry-Diagnosis, Bionomies and Control. *J. Scienti.& Ind. Res.* **30**:131–146.

Ananthakrishnan, T. N., 1973. *Thrips: Biology and Control.* Macmillan, India, p 120.

Ananthkrishnan, T. N., Thrips and Pollination Biology. *Curr. Sci*, **51**:168-172.

Ananthakrishnan, T. N., 1983. *Bioecology of Thrips.* Indira Publishing House, Michigan, p 233.

Ananthakrishnan, T. N., 1984. *Biology of Gall Insects.* Oxford & IBH, New Delhi. p 363.

Ananthakrishnan, T. N., 1989. *Bioresources Ecology.* Oxford & IBH, New Delhi, p 225.

Ananthakrishnan, T. N., 1992. *Dimensions of Insect-Plant Interactions.* Oxford & IBH, New Delhi, p 184.

Ananthakrishnan, T. N., 1993. *Chemical Ecology in Thrips – Host Plant Interactions.* Oxford & IBH, New Delhi, p 125.

Ananthakrishnan, T. N., 1994. *Functional Dynamics of Phytophagous Insects*, Oxford and IBH, New Delhi, p 304.

Ananthakrishnan, T. N., 1995. *Biological Control of Social Forest and Plantation Crop Insects.* Oxford & IBH, New Delhi, p 225.

Ananthakrishnan, T. N., 1996. *Forest Litter Insect Communities: Biology and Chemical Ecology.* Oxford & IBH, New Delhi, p 174.

Ananthakrishnan, T. N., 1998. *Technology in Biological Control.* Oxford & IBH, New Delhi, p 125.

Ananthakrishnan, T. N., 2001. *Insects and Plant Defense Dynamics.* Oxford & IBH, New Delhi, p 253.

Ananthakrishnan, T. N., 2002. *Insects, Plants and Molecular Interactions.* Madras Science Foundation, p 120.

Ananthakrishnan, T. N. and T. R. Viswanathan, 1983. *General Animal Ecology*, 2nd Edition, Macmillan India Ltd., p 356.

Ananthakrishnan, T. N. and Alok Sen, 1998. *Biocommunication in Insects*. Oxford & IBH, New Delhi, p 104.

Ananthakrishnan, T. N. and A. Raman, 1989. *Thrips and Gall Dynamics*. Oxford & IBH, New Delhi, p 120.

Ananthakrishnan, T. N. and A. Raman, 1993. *Chemical Ecology and Phytophagous Insects*. Oxford & IBH, New Delhi, p 332.

Ananthanarayanan, K. P. and E. V. Abraham, 1955. The slug caterpillar *Parasa lepida* and its control. *J. Bombay Nat. Hist. Soc.* **53**: 205-9.

Ananthasubramaniam, K.S. and T.N. Ananthakrishnan, 1975. Taxonomic, Biological and Ecological Studies on some Indian Membracids (Insecta: Homoptera, Pt 1 and 2. *Rec. Zool. Sur. India*, **63**: 161-272 and 305-340.

Anderson, D. T., 1966. The comparative embryology of the Diptera. *Ann. Rev. Ent.*, **11**: 23-46.

Anderson, S. O. and T. Weiss-fogh, 1964. Resilin–a rubber-like protein in arthropod cuticle. *Advances in Insect Physiology*, **2**: 1-65.

Anonymous, 1962. Instructions for the safe use of pesticides. Directorate of Plant Protection, *Quarantine and Storage, Govt. of India*, pp 1-8.

Anonymous, 1964. *Entomology in India*, 1938-1963. *Published by Entomological Society of India.* New Delhi, p. 529.

Armalogos, G. J. and J.R. Dewey, 1970. Evolutionary response to human infectious diseases. *Bioscience*, **20**: 271-5.

Atwal, A.S. and G.S. Dhaliwal, 1993. *Agricultural Pests of South Asia and their Management.* Kalyani Publishers, Ludhiana, p 484.

Ayyappa, P. K., S. L. Perti and Y. C. Wal, 1964. A life history study of the black carpet beetle, *Attagenus alfierii* Pic. (Coleoptera: Dermestidae). *Indian J. entomol.*, **26**: 275- 80.

Ayyar, G. R., 1961. Studies on the hairy caterpillar pests of cardamom in Kerala. *Agric. Res. J. Kerala*, **1**: 18-31.

Ayyar, P. N. K., 1930. A note on *Stibaropus tabulatus*, a new pest of tobacco in South India. *Bull. Ent. Res.*, **21**: 29-31.

Ayyar, T. V. R., 1963. *Handbook of Economic Entomology for South India.* 2 ed., Supdt., Govt. Press, Madras.

de Bach, P. and E. I. Schlinger. 1964. *Biological Control of Insect Pests and Weeds.* Chapman and Hall, London, pp 1-844.

Banerjee, B. and N. N. Kakoti, 1968. Biology, population cycle and control of *Ragmus importunitas. Indian J. entomol.*, **30**: 257-62.

Bastock, M., 1967. *Courtship.* Heineman Educational Books, L.W., London, pp 1-220.

Batra, S. W. T., 1966. Nests and social behaviour of halictine bees of India (Hymenoptera: Halictidae). *Indian J. entomol.*, **28**: 375-99.

Batra, S.W.T., 1997. Bees of India (Apoidea), their behaviour, management and a key to the genera. *Oriental Insects* **11**: 289-324.

Beeson, C.F.C., 1941. *The Ecology and Control of the Forest Insects of India and the Neighbouring Countries. (1961 reprint).* Govt. of India, New Delhi p 767.

Berozoa, M., 1970. *Chemicals Controlling Insect Behaviour.* Academic Press, N.Y. pp 1.170.

Bhatia, D.R. and M.V. Venkatesh, 1969. Some observations on the Bombay locust, *Patanaga succincta* (Linn.) in India. *Indian J. Etomol.*, **31**: 297-310.

Bhatia, S. K. and Y. Mahto, 1968. Note on breeding of fruitflies *Dacus citiatus* Loew and *D. cucurbitae* Coquillett in stem galls of *Coccinia indica* W. and A. *Indian J. entomol.*, **30**: 244-5.

Bhattacherjee, N. S. and M. G. R. Menon, 1964. Bionomics, biology and control of *Hymenia recurvalis* (Fabricius) (Pyralidae: Lepidoptera) *Indian J. entomol.*, **26**: 176-83.

Bindra, O. S. and B. Singh, 1969. Biology and bionomics of *Hishimonous phycitis*, a jassid vector of little leaf disease of brinjal *(Solanum melongena). Indian J. Agric. Sci.*, **39**: 912-9.

Bindra, O. S. and H. Singh, 1969. Phycitid pod borer *Etiella zinckenella, Pesticides*, **3**: 14-7.

Bindra, O. S. and J. Singh, 1970. Biology and bionomics of *Orossius Albicinctus*, the jassid vector of *Sesamum* phyllody virus. *Indian J. Agric. Sci.*, **40**: 340-55.

Bisht, R. S. and Man Mohan, 2001. Bioecology of *Stenopsyche Haimavatika. India J. Entomol.*, **63**: 1-7.

Browne, 1968. *Pests and Diseases of Forest Plantation Trees.* Clarendron Press, Oxford, p 1330.

Bogawat, J. K. and S. N. Pandey, 1967. Food preference in *Aulacophora* spp. *Indian J. entomol.*, **29**: 349-52.

Bonror, D. J. and D. M. DeLong, 1954. *An Introduction to the Study of Insects*, Holt, Reinhart and Winston, N.Y., pp 1-819.

Brooks, M. A., 1970. Comments on the classification of intracellular symbionts of cockroaches, and a description of the species. *J. Insect Pathol.*, **16**: 249-58.

Bradoo. B. L. and K. J. Joseph, 1970. Life-history and habits of *Oligotoma greeniana* Enderlein (Oligotomatidae: Embioptera) commensal in the nest of social spider *Stegodyphus sarassinorum* Karsch. *Indian J. entomol.*, **32**: 16-21.

Brazzel J. R., W. W. Watson, J. S. Hursh and M. H. Adair, 1968. The relative efficiency of aerial application of ultra-low volume and emulsifiable concentrate formulations of insecticides *J. Econ. entomol.*, **61**: 408-12.

Brown, F. A. Jr., J. W. Hastings and J. D. Palmer, 1970. *The Biological Clock*, Academic Press. N.Y., pp 1-94.

Bursell, R., 1970. *An Introduction to Insect Physiology*, Academic Press. N.Y., pp 1-276.

Busvine, J. R., 1966. *Insects and Hygiene*, Methuen & Co. Ltd., London, pp 1-467.

Chandrika, S. and M. R. G. K. Nair, 1972. Biology and control of *Pauropsylla brevicornis* Crawford, a pest of mango in Kerala. *Indian J. Entomol.*, **34**: 360-362.

Chapman, R. F., 1969. *The Insects, Structure and Function.* The English Universities Press Ltd., London, pp 1-819.

Chatterjee, N. C., 1933. Entomological investigations on the spike disease of sandal : the life history and morphology of *Euryrachus temontosa. Indian For. Rec.*, **18**: 1-25.

Chaudhury. J. P. and M. Ramzan, 1968. *Pachygonatopus* sp. (Dryinidae: Hymenoptera), a new parasite of *Sogatella furcifera* Howth (Delphacidae: Homoptera). *Indian. J. entomol.*, **30**: 317.

Chaudhury, J. P., M. Ramzan and A. S. Atwal, 1969. Preliminary studies on the biology of wheat aphids. *Indian J. Agric. Sci.*, **39**: 672-5.

Cherian, M. C., 1934. Notes on some South Indian syrphids. *J. Bombay Nat. Hist. Soc.*, **37**: 697-9.

Cherian, M. C. and K. P. Ananthanarayanan, 1939. Studies on the coconut palm beetle (*Oryctes rhinoceros* Linn.) in South India. *Indian J. Agric. Sci.*. **9**: 541-59.

Cherian, M. C. and M. Basheer, 1940. *Euborellia stalli* as a pest of groundnuts in South India. *Indian J. entomol.*, **2**: 155-8.

Cherian, M. C. and M. S. Kylasam, 1947. Studies on the spotted bollworms of cotton *Earias fabia* and *Earias insulana*. *J. Bombay Nat. Hist. Soc.*, **46**: 658-67.

Cherian, M. C. and C. V. Sundaram, 1939. Notes on the life history and habits of *Dacus brevistylus* Bezzi (Family: Trypetidae) a pest of *Coccinia indica* fruits. *Indian J. Agric. Sci.*, **9**: 127-31.

Chitriv, A. J., 1970. Lemon butterfly *Papilio demoleus. Pesticides*, **4**: 15-6.

Christianson, K., 1964. Bionomics of Collembola. *Ann. Rev. Ent.*, **9**: 147-78.

Clark, L. R., P. W. Geier, R. D. Hughes and R. F. Morris, 1968. *The Ecology of Insect Population.* Methuen and Co. Ltd., London., pp 1-232.

Comstock, J. H., 1949. *An Introduction to Entomology*, Comstock Pub. Co., Ithaca. pp 1-1064.

Dandin, S. B., Jayant Jayaswal and K. Giridar. (eds.), 2001. *Handbook of Sericulture Technologies.* Central Silk Board, Bangalore, p 287.

Danthanarayanan, W. and S. N. Feranado, 1970. A method of controlling termite colonies that live within plants. *Internat. Pest Control*, **12**: 10-14.

Das, N. M. and M. R. G. K. Nair, 1966. Control of the sweet potato weevil *Cylas formicarius* Fb. with some of the newer synthetic insecticides. *Agric. Res. J. Kerala*, **4**: 78-81.

Das, N. M., K. S. Remamony and M. R. G. K. Nair, 1968. On the control of the melonfly *Dacus cucurbitae* Coquillett with some newer synthetic insecticides applied as cover sprays. *Agric. Res. J. Kerala*, **6**: 43-5.

Das, N. M., K. S. Remamony and M. R.G. K. Nair, 1969. Biology of a new jassid pest of mango, *Amrasca splendens* Ghauri. *Indian J. entomol.*, **31**: 288-289.

Davey, K. G., 1965. *Reproduction in the insects.* W. H. Freeman and Co., San Francisco, pp 1-96.

David, B. V., 1960. *Plusia ni* as a pest of cabbage *Brassica oleracea* in South India. *J. Bombay Nat. Hist. Soc.* **57**: 679-81.

David, B. V., 1987. First record of the whitefly subfamily Aleurodicinae (Aleyrodidae: Homoptera) from India. *Curr. Sci.*, **56**: 1247-1248.

David, B. Vasantharaj, 2001. *Elements of Economic Entomology*. Popular Book Depot, Chennai 600015, p 590.

David, B. V. and S. K. David, 1961. Lepidopterous larvae injurious to sorghum earheads. *Madras agric. J.*, **48**: 93-97.

David, B. V. and V. David, 1961. *Spatulicraspeda castaneiceps*, the humped slug caterpillar of tea as pest of castor in South India. *Bull. Ent.*, **2**: 30-31.

David, B. V. and A. Janagarajan, 1969. Notes on pests of Safflower in Tamil Nadu. *Madras agric. J.*, **56**: 534-538.

David. B. V., T. Kumaraswami and M. Mohanasundaram, 1962. Caterpillar pests of Ragi (*Eleusine coracona* Gaertn.) ears in South India, *Madras agric. J.*, **49**: 265-267.

David, B.V., P. S. Narayanaswamy and M. Murugesan, 1964. Bionomics and control of the castor shoot and capsule borer *Dichocrocis (Conogethes) punctiferalis* Guen. (Lepidoptera : Pyralidae) in Madras State. *Indian Oilseeds J.*, **8**: 146-158.

David, B.V. and A.V. Rangarajan, 1966. Insects affecting *Barleria* spp. in Coimbatore. *Indian J. Hort.*, **23:** 191-195.

David, B.V., A.V. Rangarajan and P.S. Narayanaswamy, 1964. The biology of the Buprestid leaf miner *Trachys* sp. a new pest on *Barleria cristata* Linn. *Madras agric. J.*, **51:** 166-172.

David, B.V. and K. Regu, 1995. *Aleurodicus dispersus* Russell (Aleyrodidae: Homoptera) a whitefly pest new to India. *Pestology* **19** (**3**): 5-7.

David, B.V. and T. Santhanaraman, 1964. First record of the green nettle slug caterpillar *Thosea aperiens* Wlk. in India. *Madras. agric. J.*, **50**: 499-502.

David, B.V. and T.R. Subramaniam, 1962. A note on the occurrence of a Lepidopterous borer on snakegourd vines. *Madras agric. J.*, **49**: 192-193.

David, B.V. and T. R. Subramaniam, 1976. Studies on some Indian Aleyrodidae. *Rec. Zool, Surv. India*, **70**: 133-233.

David, B.V., D. Sukumaran and C. Kandasamy, 1988. The Indian Privet *Vitex negundo* Linn.—A plant possessing promising pesticidal activity. *Pesticides* **22** (**2**): 27-30.

David, H., S. Easwaramoorthy and R. Jayanthi (eds.), (1986) *Sugarcane Entomology in India.* Sugarcane Breeding Institute, Coimbatore publn., p. 559.

Day, P. K., S. A. Rudgard and K. S. Nair, 1994. Asian Pests. *FORSPA publication 12, FAO*, *Bangkok*, p 71.

Dent, D., 1993. *Insect Pest Management.* CAB International, Wallingford, U.K., p 604.

Devasahayam, S., 1999. Integrated management of major insect pests of spices—Black pepper, Ginger and Turmeric. *IPM System in Agriculture. Vol.6*, *Cash Crops*, Eds. Rajeev, K., Upadhyay, K.G. Mukerji and O.P. Dubey, Aditya Books Pvt. Ltd., New Delhi, pp 369-380.

Devasahayam, S. and K. M. Abdulla Koya, 1999. Integrated management of Insect Pests in Spices. *Indian J. Acrecanut, Spices & Medicinal Plants*, **1**: 19-23.

Devasahayam, S. and O.P. Dubey, 1999. Integrated management of major insect pests of Cardamom. *IPM System in Agriculture*, *Vol.6*, *Cash Crops*, Eds. Rajeev, K., Upadhyay, K.G. Mukerji and O. P. Dubey, Aditya Books Pvt. Ltd., New Delhi, pp 423-432.

Devasahayam, S., T. Premkumar and K. M. Abdulla Koya, 1988. Insect Pests of Black Pepper *Piper nigrum* L. in India. *J. Plantation Crops* **16:** 1-11.

Dhaliwal, G. S. and R. Arora, 1996. *Principles of Insect Pest Management.* National Agricultural Technology Information Centre, Ludhiana, p 372.

Dhaliwal, G. S. and E. A. Heinrichs, 1998. *Critical issues in Insect Pest Management.* Commonwealth Publishers, New Delhi, p 287.

Dover, C., 1924. Some observations on the bionomics of *Xylocopa aestuans* Linn. (Apidae). *Trans. Entl. Soc., London.* Parts I & II, pp 144-149.

Duval, C. T., 1970. Some introductory aspects of chemical relationships and the nomenclature of systemic organic insecticides. *PANS*, **16**:11-35.

Engelmann, F., 1970. *The Physiology of Insect Reproduction*, Pergamon Press, London, pp 1-307.

Essig, E. O., 1942. *College Entomology*, Macmillan. N.Y., pp 1-900.

Etheridge, P. and I. J. Graham-Bryce, 1970. Influence of soil moisture on the performance of granular systemic insecticides applied to soil. *Ann. Appl. Biol.*, **65**: 15-23.

Finney, D. J., 1971. *Probit Analysis.* 3rd edn., Cambridge Univ. Press., Cambridge.

Fox, R. M. and J. W. Fox. 1964. *Introduction to Comparative Entomology,* Reinhold Publishing Corporation, N.Y., pp 1-450.

Ganguli, R. N., 1961. Biology and control of *Eurema blanda silhetana,* a pest on shade trees in tea gardens. *Indian J. entomol.*, **23**: 195-201.

George Koshy, A. Visalakshy and M. R. G. K. Nair, 1977. Biology of *Acanthocoris scabrator* Fabr., a pest of mango *Entomol.* **2**: 145-147.

Goodchild, A. J. P., 1963. Some new observations on the internal structures concerned with water disposal in plant sucking Heteroptera. *Trans. Roy. Ent. Soc., London*, **115**: 217-37.

Gupta, R. P., K. M. Rai and N. K. Joshi., 1969. Efficiency of some modern insecticides against woolly apple aphis *Eriosoma lanigerum. Indian J. entomol.*, **31**: 174-5.

Hadom, E., 1965. Problems of determination and transdetermination. *Brookhaven Symposia in Biology*, **18**: 148-61.

Hadorn, E., 1968. Transdetermination in cells. *Scient. Amer.*, **219**: 110-23.

Harrington, R. and N. E. Stork, 1995. *Insects in a Changing Environment.* Academic Press, London, p 535.

Harris, K. M., 1969. The sorghum midge. *World Crop*, **21**: 176-9.

Haskell, P. T., 1961. *Insect Sounds*, H. F. and G. Witherby, London.

Haskell, P. T., 1966. Insect behaviour. *Roy. Ent. Soc., London*, pp 1-113.

Hawkins, B. A. and W. Sheehan, 1994. *Parasitoid Community Ecology.* Oxford University Press, New York, p 516.

Highnam, K. C. and L. Hill, 1969. *The Comparative Endocrinology of Invertebrates*, E. Arnold, London, pp 1-270.

Imms, A. D., 1963. *A General Textbook of Entomology*, revised by O. W. Richards and R. G. Davies. Asia Publishing House, pp 1-886.

Inderpal Singh and Gurdip Singh, 1995. Biology of Bihar hairy caterpillar, *Spilosoma obliqua* Walker on sunflower in Punjab. *J. Insect Sci.*, **8:** 48-54.

Isman, M. B., 2002. Insect Antifeedants *Pesticide Outlook*, *August* 2002, pp 152-157.

Isman, M. B., H. Matasuura, S. MacKinnon, T. Durst, G.H.N. Towers and J.T. Arnason, 1996. Phytochemistry of the Meliaceae: So many terpenoids, so few insecticides. *Recent Advances in Phytochemistry*, **30**: 155-178.

Jayanth, K. P., 1987. Biological Control of Water Hyacinth in India. *Technical Bulletin No.3,* Indian Institute of Horticutural Research, Bangalore. p. 28.

Jayaraj. S, Ananthakrishan T. N. and G. K. Keeresh, 1994. *Biological Pest Control in India: Progress and Perspectives.* Rajiv Gandhi Institute of Contemporary Studies, New Delhi, p 101.

Jeannel, R., I960. *Introduction to Entomology*, Hutchinson, pp 1-344.

Jeyaraney Kathirithamby, 1989. Review of the Order Strepsiptera. *Systematic Entomology* **14**(**1**): 41-92.

Jones, J. C., 1968. The sexual life of a mosquito. *Scient. Amer.*, **218**: 108-16.

Jones, M. T. and R. F. Harwood, 1969. *Herms' Medical Entomology*, MacMillan Co., N. Y., p 1484.

Joshi, R. G. and M. V. Pavate, 1963. Studies on the biology of tobacco ground beetle *Mesmorphus Villiger* Blanch by periodic regression analysis. *Indian J. Entomol.*, **25**: 1-8.

Jotwani, M. G. and P. Sircar, 1967. Neem seed as a protectant against stored grain pests infesting wheat seed. *Indian J. Entomol.*, **27**: 160-64.

Jotwani, M. G. and P. Sircar, 1967. Neem seed as a protectant against bruchid *Callosobruchus Maculatus* infesting some legumenous seeds. *Indian J. Entomol.*, **29**: 21-4.

Kalra, A. N., 1970. Efficiency of endrin and endosulfan granules in controlling top borer of sugarcane. *Indian Sugar*, **20**: 185-6.

Kalra, A. N., H. David and D. K. Banerjee, 1969. Preliminary observations on the Cuban fly *Lixophaga Diatriae*, an exotic parasite of moth borers. *Indian Sugar*, **19**: 183-90.

Khalsa, H. G., R. S. Nigam and P. N. Agarwal, 1965. Resistance of coniferous timbers to *Lyctus* attack. *Indian J. Entomol.*, **27**: 3 77-88.

Khan, Q. and V. P. Rao, 1960. *Insect and Mite Pests in Cotton in India*, Monograph. Vol. 2: ICCC, pp 217-301.

Kilgore, W. W. and R. L. Doutt, 1967. *Pest Control.* Academic Press, N.Y., pp 1-477.

King, R. C., 1970. *Ovarian Development in Drosophila melanogaster.* Academic Press, N.Y., pp 1-227.

Krishnaswami, S., M. R. Ghosh, N. Majumdar and Y. S. Krishnan, 1963. An abnormal incidence of *Holotrichia serrata* (F.) (Melolonthidae: Coleoptera). *Indian J. Entomol.*, **25**: 381-2.

Kumar, H.D., 2000. *Plant–Animal Interactions.* Affiliated East-West Press, New Delhi, p 400.

Kumaresan, D., A. Regupathy and P. Baskaran, 1998. *Pests of Spices*, Rajalakshmi Publications, Nagercoil, p 241.

Lakra, R. K. and Zile Singh, 1983. Oviposition behaviour of *Ber* fruitfly, *Carpomyia vesuviana* Costa and relationship between its incidence and ruggedness in fruits in Haryana. *Indian J. entomol.*, **45**: 48-59.

Langbridge, D. M., 1970. The protection of packaged foods from insect attack. *Pyrethrum Post*, **10**: 6-9.

Leach, J. G., 1940. *Insect Transmission of Plant Diseases.* McGraw-Hill Publishing Co.. N. Y., pp 1-615.

Lindauer, M., 1961. *Communication among Social Bees.* Harvard University Press, Cambridge, pp 1-143.

MacCuaig, R. D., 1969. Locust control and the development of ultra-low volume spraying. CIBA *Agrochemical Division Technical Monograph*, pp 2-8.

Madhukar, B. V. R. and M. K. K. Pillay, 1970. Development of organophosphorus resistance in Indian strains of *Aedes aegypti* (L). *Bull. Wld Health Org.*, **43**: 775-42.

Majumdar, N. and T. P. S. Teotia, 1965. Biology of *Holotrichia serrata* (Fabricius) a serious pest of *Palas* (*Butea monosperma*). *Indian J. entomol.*, **27**: 153-9.

Mani, M. S., 1939. Descriptions of new and records of some known chalcidoid and other Hymenopterous parasites from India. *Indian J. entomol.*, **1**: 69-99.

Mani, M. S., 1968. *General Entomology*, Oxford and IBH Pub. Co., pp 1-501.

Marc E. Epstein, 1995. Evolution of locomotion in slug caterpillars (Lepidoptera: Zygaenoidea: Limacodid group. *J. Res. Lepidoptera*, **34**: 1-13.

Mathen, K. and C. Kurien, (1967). Insecticidal trials against *Rhynchophorus Ferrugineus* Fabr. (Curculionidae: Coleoptera) the red weevil of coconut. *Indian J. Agric. Sci.*, **37**: 521-3.

Matsumura, Fumio, 1985. *Toxicology of Insecticides.* Plenum Press, New York and Longon, p 598.

Mazokim-Porshnyakov, G. A., 1969. *Insect Vision.* (translated). Plenum Press. N. Y., pp 1-306.

Menon, M. G. R. and Baldev Parshad, 1960. An interesting antennofrontal stridulatory mechanism in a gryllid *Loxoblemmus equestris* Saussme (Orthoptera). *J. Anim.Morph. Physiol.*, **7**: 167-9.

Menon, M. G. R. and S. Ghai, 1959. A new species of *Gampsocoris* (Hemiptera : Berylidae) from Delhi. *Proc. Roy. Ent. Soc., London*, B. **28**: 109-13.

Menon, M. G. R., Y. P. Beri and S. S. Misra, 1968. Records of pupiparous Diptera (Hippoboscidae) on birds in India III. *Indian J. entomol.*, **30**: 242.

Metcalf, C. L. and W. R. Flint, 1962. *Destructive and Useful Insects, their Habits and Control*, 4th ed, McGraw-Hill Book Co. Inc., pp 1-1087.

Miller, J. R. and R. S. Cowles, 1990. Stimulo-deterrent diversion: A concept and its possible application to onion maggot control. *Journal of Chemical Ecology*, **16**: 3197-3212.

Mohanty, P.K., 1998 *Tropical Tasar Culture in India.* Daya Publishing House, New Delhi, p 153.

Mookerjee, P. B., Y. P. Peri, G. C. Sharma and R. S. Dewan, 1965. Preliminar, studies on the efficacy of malathion against *Sitophilus oryzae* and *Tribolium castaneum* and its persistence in stored wheat. *Indian J. entomol.*, **27**: 476-480.

Mote, U. N., D. S. Ajri and A. B. Tambe, 1992. An annotated list of pests infesting Pomegranate in Central Maharashtra. *Maharashtra J. hortic.*, **6**: 96-98.

Muniyappan, R., 1974. Biology of the Poinciana Looper, *Pericyma cruegeri* (Butler) on Guam. *Micronesica*, **10**: 273-278.

Muraleedharan, N., 1991. Pest Management in Tea. *UPASI Tea Res. Inst., Valparai.* p 130.

Muraleedharan, N. and B. Radhakrishnan, 1991. Observations on the ecology and control of the coffee berry borer. *The Planter's Chronicle, Nov. 1991*, pp 573-575.

Nair, K. S. S., J. K. Sharma and R.V. Varma. (eds), 1996. Impact of Diseases and Insect Pests in Tropical Forests. *Kerala Forest Res. Inst. publication.* p 521.

Nair, M. R. G. K., 1958. The biology and control of rice stalk borer *Proceras polychrysa* from Kerala. *Indian J. entomol.*, **30**: 136-41.

Nair, M. R. G. K. and N. Mohandas, 1962. On the biology and control of *Carvalhoeia arecae*, a pest of areca palms in Kerala. *Indian J. entomol.*, **24**: 86-93.

Nair, M. R. G. K., A. Visalakshi and George Koshy, 1980. A new root-infesting mealy bug of coconut. *Entomon*, **5:** 245-246.

Narayanan, K. and C. Gopalakrishnan, 1988. *Microbial Control of Heliothis armigera.* Indian Institute of Horticultural Research, Bangalore., p 44.

Narayanswamy, P. S. and V. Mahadevan, 1965. Bee-keeping in South India. *Advances in Agricultural Sciences and Their Applications*, pp 657-66. Madras Agricultural Students' Union Publn, Coimbatore.

Nath, D. K. and A. C. Basu, 1969. Observations on the behaviour of orange trunk borer, *Anoplophora versteegi* (Pits) (Lamiidae: Coleoptera) in Darjeeling hills. West Bengal, *Indian J. Ahgric. Sci.*, **39**: 713-7.

Nayar, K. K., 1958. Studies on the neurosecretory system of *Iphita limbata* V. Probable endocrine basis of oviposition in the female insect. *Proc. Indian Acad. Sci.*, **B47**: 233-51.

Newton Harvey, E., 1956. Evolution and Bioluminescence. *The Quarterly Review of Biology* **31**: 270-287.

Noble, E. R. and G. D. Noble, 1965. *Parasitology*, Lea and Febiger, Philadelphia, pp 1-724.

Novak, V. J. A., 1966. *Insect Hormones.* Methuen and Co., pp. 1-478.

Oommen, C. N., 1962. Studies on *Phycita orthoclina* Meyr. (Lepidoptera: Pyralidae). A new pest of tamarind fruit in Kerala. *Indian J. entomol.*, **24**: 188-190.

Opender Koul and G. S. Dhaliwal, 2001. *Phytochemical Biopesticides.* Harwood Academic Publishers, Amsterdam, p 223.

Panda, N. and G. S. Khush, 1995. *Host plant Resistance to Insects.* CAB International, Wallingford, U. K., p 430.

Pandey, N. D., S. C. Mitra and U. K. Pandey, 1978. Some observations on the biology of *Polyommatus boeticus* (Linn.) (Lepidoptera: Lycaenidae) a pest of *Cajanus cajan* (L.) Millsp. *Indian J. entomol.*, **40:** 80-81.

Pandey, N. D. and Y. D. Pandey, 1964. Bionomics of *Phyllocnistis citrella. Indian J. entomol.*, **26**: 417-22.

Parel, C. F., P. N. Agarwal and Ali Ausat, 1965. Toxicity of solvent extract of *Acorus calamus* to some grain pests and termites. *Indian J. entomol.*, **27**: 114-7.

Patel, B.H., V.R. Upadhyay, C.M. Muralidharan and G.S. Judal, 1989. Comparative efficacy of different insecticides against Ber fruitfly *Carpomyia vesuviana* Costa. *Indian J. Pl. Prot.*, **17**: 39-45.

Pathummal Beevi, S., C. C. Abraham and K. V. Peter (eds.), 2000. *Biological Control of Crop Pests In Kerala.* Directorate of Research, Kerala Agricultural University, Vellanikkara, 680656, Kerala, p 105.

Patton, R. L., 1963. *Introductory Insect Physiology*, W. R. Saunders Co., Philadelphia, pp 1-245.

Paul, A.V. N. and B.V. David, 1975. Record of the Greenhouse whitefly *Triaelurodes vaporariorum* (Westwood) on tomato. *Current Sci.*, **44**: 104-105.

Paul, C. F., G. N. Sukia, S. R. Das and S. L. Perti, 1962. A life history study of the hide beetle *Dermestes Vulphinus* Fab. (Coleoptera: Dermestidae). *Indian J. Entomol.*, **24**: 167-79.

Poner, M. P., 1964. The gynandromorphs of *Schistocerca gregaria* Forskal (Orthoptera : Acridoidae). Morpholopy and behaviour. *Proc. Roy. Ent. Soc., Lond., (A)* **39**: 89-100.

Pereira, N. and H. E. Fernando, 1970. Infestation of young rice plants by the rice gall midge *Pachydiplosis oryzae* (Wood-Mason) (Dipt. Cecidomyiidae) with special reference to shoot morphogenesis. *Bull. Ent. Res.*, **59**: 605-13.

Ponnaiya, B. W. X., 1951. Studies on the genus *Sorghum*-Resistance to the Insect pest *Atherigona indica. Madras Univ. J.*, **21**: 203-217.

Popham, E. J., 1961. The function of Hagemann's organ in *Corixa punctata. Proc. Roy. Ent. Soc., London,* **A 36**: 119-125.

Pradhan, S., 1969. *Insect Pests of Crops,* National Book Trust of India, New Delhi, pp 1-280.

Pranab Roy and S. K. Basu, 1977. Bionomics of aphidophagous syrphid flies. *Indian J. entomol.*, **39**: 165-174.

Prasad, S. N., 1966. Biology of *Erosomyia indica* Grover– the most serious pest of mango in India. *Cecid. Indica*, **1**: 1-24.

Prasad, S. N., 1966. Biology of *Dasineura citri* Grover– the citrus blossom midge. *Cecid. Indica*, **1**: 33-58.

Prasad, S. N. and P. Grover, 1966. Gall midges of economic importance IV. Biology of gall midges (Cecidomyiidae: Diptera) affecting mango inflorescence. *Cecid. Indica*, **1**: 51-68.

Prem Kishore, M. G. Jotwani and G. G. Kundu, 1977. Bionomics of wheat shootfly, *Atherigona naqvii* Steyskal, a new pest of wheat. *Indian J. entomol.,* **39**: 17-22.

Prem Kumar, T., S. Devasahyam and K. M. Abdulla Koya, 1994. Pests of Spice Crops. *Advances in Horticulture* ***Vol. 10****—Plantation and Spice Crops Part 2 (1994)*, Eds. K. L. Chadha and P. Rethinum.

Price, P. W., 1970. Trail odours: recognition by insects parasitic on cocoons. *Science*, **170**: 546-7.

Pruthi, H. S., 1960. *Text Book on Agricultural Entomology*, Indian Council of Agricultural Research, New Delhi, pp 1-979.

Puttarudriah, M. and S. Usman, 1957. Flood causes army worm outbreak. *Mysore Agric. J.*, **32**: 124-31.

Rahman, K. A. and A. W. Khan, 1941. Biology and control of woolly aphis *Eriosoma lanigerum* in the Punjab. *Indian J. Agric. Sci.*,**11**: 265-78.

Rajasekhara K., S. Chatterji and M. G. R. Menon, 1964. Biological notes on *Psallus* species, a predator of *Taeniothrips nigricornis. Indian J. entomol.*, **26**: 62-6.

Raina, S. K. and W. A. Overholt, (Eds.). 1996. *Conservation of Hymenopteran Parasitoids for Management of the Citrus Blackfly in Oranges.* Nagpur University, Nagpur, p 78.

Rao, S. N., 1955. Catalogue of Oriental Itonididae (Cecidomyiidace: Diptera), *Agra Univ. J. Res. (Science)* **4**: 213-282.

Rao, V. P., 1964. A new record of the carabid beetle *Pherosophus sorripus* (Desj.) var. *desbordesi* (Maindr.) as a predator of the rhinoceros beetle *Oryctes rhinoceros* Linn.) in India. *Tech. Bull. Commonwealth Institute for Biological Control.* **4**.

Rao, V. P., 1965. Natural enemies of rice stem borers and allied species on various parts of the world and possibilities of their use in biological control of rice stem borers of Asia. *Tech. Bull. No.6, B. C.,* 1-68.

Rao, V. P., 1969. Biological control of stalk moth bores in the Old World–Part 1. *Indian Sugar*, **18**: 813-23.

Rao, Y. R., 1961. Notes on the life history and habits of *Chonocephalus depressus* De Meijere (Diptera: Phoridae) in South India. *Proc. Roy. Ent. Soc., London, A* **36**:163-7.

Regu, K. and B.V. David, 1993. Taxonomic studies on Indian aleyrodids of the tribe Aleurolobini (Aleyrodidae: Homoptera). *FIPPAT Entomol. Ser.*, **4**: 1-79.

Regupathy, A. and K. P. Dhamu, 2001. *Statistics Work Book for Insecticide Toxicology.* Softeck Computers, 55 Rathinapuri, Coimbatore 641027, p 206.

Regupathy, A., S. Chandrasekaran, T. Manoharan and S. Kuttalam, 1996. *A guide on Forest Entomology.* Sorriya Desktop Publishers, Coimbatore, p 206

Regupathy, A., S. Palanisamy, N. Chandradmohan and K. Gunathilagaraj, 2003. *A Guide on Crop Pests.* Sheba Printers, Combatore 641027, p 276.

Reitz, L. P., 1960. *Biological and Chemical control of Plant and Animal Pests.* American Association for Advancement of Science (Washington), pp 1-273.

Reotra, T. P. S. and S. Nand, 1966. Bionomics of the rice skipper *Parnara mathias. Indian J. entomol.*, **28**:181-6.

Reynolds, H. T., 1958. Research advances in seed and soil treatment with systemic and nonsystemic insecticides. *Adv. Pest. Control Res.*, **2**: 135-82.

Riddiford, L. M. and C. M. Williams, 1967. Volatile principle from oak leaves: role in sex life of *Polyphemus* moth. *Science*, **155**: 589.

Ripper, W. E., 1957. The status of the systemic insecticide in pest control practices. *Adv. Pest Control Res.*, **1**: 305-52.

Roitberg, D. B. and M. B. Isman, 1992. *Insect Chemical Ecology.* Chapman & Hall, New York, p 360.

Roth, L. M., 1967. Uricose glands in *Blattaria. Ann. Ent. Soc. Amer.*, **60**: 1203-11.

Roth, L. M., 1967. Water changes in cockroach oothecae in relation to the evolution of ovoviviparity and viviparity. *Ann. Ent. Soc. Amer.*, **60**: 928-46.

Roth, L. M., 1968. Ovarioles of *Blattaria. Ann. Ent. Soc. Amer.*, **61:** 132-40.

Roth, L. M., 1968. Oothecae of *Blattaria. Ann. Ent. Soc. Amer.*, **61:** 83-111.

Roth, L. M. 1969. The evolution of male tergal glands in the *Blattaria. Ann. Ent. Soc. Amer.*, **62**: 176-208.

Roth, L. M. and G. P. Dateo, 1964. Uric acid in the reproductive system of males of the cockroach *P. germanica. Science*, **146**: 782-4.

Roth, L. M. and G. P. Dateo, 1966. A sex pheromone produced by males of the cockroach *Nauphoeta cinerea. J. Insect Physiol.*, **12**: 255-65.

Roth, L. M. and E. R. Willis, 1954. The reproduction of Cockroaches. *Smiths Misc. Coll.,* **122** (5): 1-49.

Rothschild, M., B. Ford and M. Fuches, 1970. Maturation of the male rabbit flea (*Spylopsyllus cuniculi*) and the oriental rat flea (*Xenopsylla cheopis*): Some effects of mammalian hormones on development and impregnation. *Trans. Zool. Soc., London,* **32**: 107- 8.

Sachav, J. N. and B. P. Srivastava., 1965. Biology of the lily moth *Polytela gloriosae. Indian J. entomol.*, **27**: 136-9.

Sah, B. N. and B. P. Mehra, 1969. Bionomics of *Hypena iconicalis* Wealker, a pest of *Moghania macrophylla* (Willd.). *Indian J. entomol.*, **31**: 354-360.

Sandhu, G. S. and P. K. Arora., 1990.Studies on mechanical and chemical control of mushroom flies-important pests of white button mushroom in the Punjab. *J. Insect Sci.*, **3**: 92-96.

Sandhu, G. S. and D. S. Brar., 1980. Biology of Sciarid fly, *Bradysia tritici* (Coq.) (Diptera: Sciaridae) infesting mushrooms. *Indian J. Mushroom* **6**: 53-63.

Satpathi, C. R., S. Pal and M. R. Ghosh 1992. List of Insects and Mites infesting Pigeonpea (*Cajanus cajan*) in West Bengal. *Ann. Entomol.*, **10(2)**: 51-53.

Saxena, D. K. 1968. Chemical control schedule for the ber fruitfly. *Indian J. entomol.*, **30**: 295-8.

Schabel, G. H., L. Hilie, K. S. S. Nair and R.V. Varma, 1999. Economic entomology in tropical forest plantations: an update. *J. Tropical Forest Sci.*, **11**: 303-315.

Selvakumaran, S., B.V. David and D. Kumaresan, 1998. Biology of the whitefly, *Kanakarajiella cardamomi* (David and Subramaniam) (Aleyrodidae: Homoptera) on cardamom. *Pest Management in Horticultural Ecosystem* **4**: 89-92.

Sen, S. K. and T. R. Fletcher, 1962. *Veterinary Entomology and Acarology for India*. Indian Council of Agricultural Research, New Delhi.

Shanower, T. G., J. A. Wightman and A. P. Gutierrez, 1993. Biology and control of the groundnut leaf miner, *Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae). *Crop Protection* **12:** 3-10.

Sharma, A. K., J. D. Saxena and H. R. Subba Rao, 1966. Catalogue of the Hymenopterous and Dipterous parasites of *Chilo zonellus. Indian J. entomol.*, **28**: 510-42.

Shorthouse, J.D. and O. Rohfritsch, 1992. *Biology of Insect Induced Galls.* Oxford University Press, New York, p 285.

Singh, S. P., 1989. Biological Suppression of Weeds. *Tech. Bull. No.1, National Centre for IPM, Faridabad.* p. 27.

Singh, S. P., 1989. Achievements of AICRP on Biological Control. *Tech. Bull. No. 2, National Centre for* Biological Control, Bangalore.

Sivagami. R. and B.V. David, 1968. Some insect pests of Moringa (*Moringa oleifera Linn.*) in South India. *South Indian Hort.*, **16:** 69-71.

Sivagami, V., B.V. David and N. Rajamohan, 1976. Pests of *Crossandra Infundibuliformis* in South India. *Pesticides* **10** **(12):** 39-40.

Snodgrass, R. E., 1935. *Principles of Insect Morphology.* McGraw-Hill Pub. Co., N.Y., pp 1-667.

Snodgrass, R. E., 1957. A revised interpretation of the external reproductive organs of male insects. *Smiths Misc. Coll.*, **135** (6): 1-60.

Snodgrass, R. E., 1961. The caterpillar and the butterfly. *Smiths Misc. Coll.*, **143** (6): 1-51.

Snodgrass, R. E., 1953. The metamorphosis of a fly's head. *Smiths Misc. Coll.*, **122**: (3): 1-25.

Sohi, A. S. and M. S. Dhooria, 1999. Insects as Human's Food. *Insect News* **2(1-2)**: 6-7.

Sohi, A. S. and A. S. Sohi (Sr.), 1990. Mango leafhoppers (Homoptera: Cicadellidae)—A review. *J. Insect Sci.*, **3**: 92-96.

Sondheimer, E. and J. R. Simeone, 1970. *Chemical Ecology*. Academic Press. N.Y., pp 1-336.

Sone Lal and R. B. Doharey, 1993. Stored grain pests of national importance and their management. *Pest* Management and Pesticides: Indian Scenario. (ed.) B.V. David, Namrutha Publications, Chennai 600040, pp 101-117.

Sood, A. K. and K. L. Kakar, 1990. Record of Insect and Non-insect pests of Ornamental Plants from Himachal Pradesh. *J. Insect Sci.*, **3**: 141-145.

Srivastava, B. K. and R. M. Khan, 1963. Bionomics and control of *Holotrichia insularis* (Melolonthidae: Coleoptera). *Indian J. entomol.*, **25**: 347-54.

Srivastava, J. S. and B. P. Pande, 1967. The tenebrionid beetle *Gonocephalus depressum* F. from poultry units as the vector of some of the larval helminths. *Indian J. entomol.*, **29**: 205-12.

Subba Rao, B. R. 1998. History of Entomology in India. Institution of Agricultural Technologists, Bangalore, p 223.

Subbiah, M. S. and V. Mahadevan, 1957. The life history and biology of the reduviid *Acanthaspis siva* a predator of the Indian honeybee *Apis indica. Indian J. Vet. Sci.*, **27**: 117-22.

Subramanian, T. R., 1959. Biology of *Alcidodes affaber* Aurivillius. *Indian J. Agric. Sci.*, **29**: 81-9.

Subramaniam, T. R., P. Narayanaswamy and V. Mariappan, 1978. *Rice Brown Planthopper and Virus diseases of Paddy*. Tamil Nadu Agricultural University, Coimbatore, p 22.

Subramanian, T. V., 1940. Bionomics of a grape boring plume moth *Oxyptilus regulus* in South India. *Bull. Ent. Res.,* **30**: 471-3.

Subramanian, T. V. and K. P. Ananthanarayanan, 1938. A note on *Metanastria hyrtaca. J. Bombay Nat. Hist. Soc.*, **40**: 257-63.

Sundarababu, P. C. and B.V. David, 1973. A note on the unprecedented occurrence of fruit-piercing moths on grapevine. *South Indian Hort.*, **21:** 134-136.

Tale, Y. M. and A. E. Rane, 1972. Biology of *Catochrysops strabo* Fabricius (Lepidoptera: Lycaenidae). *Indian J. entomol.*, **34:** 347-348.

Tandon, P.L. and A. Verghese, 1985. World List of Insect, Mite and other Pests of Mango. *Tech. Doc. No. 5*, *Indian Inst. Hort. Res.*, *Bangalore*, p 22.

Taylor, J. H., 1970. Pesticide research in developing countries. *PANS*, **16**: 423-33.

Thorpe, W. H. 1950. Plastron respiration in aquatic insects. *Biol. Rev.*, **25**: 344-90.

Tirumala Rao, V., 1952. The paddy root weevil *Echinocnemus oryzae* Mshll. – a pest of paddy in the Deltaic tracts of the Northern Circars. *Indian J. entomol.*, **14**: 31-7.

Tombes, A. S., 1970. *An Introduction to Invertebrate Endocrinology*. Academic Press, N.Y., pp 1-217.

Truman, J. W., 1970. The eclosion hormone: its release by the brain and its action on the central nervous system of silk moths. *Amer. Zoologist*, **10**: 511-2.

Tuxen, S. L., 1956. *Taxonomists Glossary of the Genitalia of Insects.* Copenhagen, pp 1-284.

Usman, S. and M. Puttarudraiah, 1955. A list of the insects of Mysore including the mites. *Dept. Agric. Mysore State, Ento. Series. Bull. No.* **16**, pp 1-194.

Uvarov, B., 1966. *Grasshoppers and Locusts.* Cambridge University Press, pp 1-480.

R.V. Varma, K.V. Bhat, E. M. Muralidharan and J. K. Sharma 2001. *Tropical Forestry Research: Challenges in the New Millennium.* Kerala Forest Research Institute, Peechi, 291 PP

Venkatesh, M.V., S. C. Harjai and Harish Chandra, 1975. Biological observations on the tree locust, *Anacridium rubrispinum* Bei-Bienko (Cyrtacanthacrinae: Acrididae). *Indian J. Entomol.*, **37**: 397-405.

Varma, R.V., 1986. Seasonal incidence and possible control of important insect pests of plantations of *Ailanthus tryphysa.* KFRI Research Report No. 39, KFRI, Peechi, p 42.

Varma, R.V., 1990. Termite problem in forest plantations and its control in India. *Sociobiology* **17**: 155-156.

Verma, J. P., V. K. Mathur, S. K. Sharma and R. R. Batra, 1969. New record of staphylinid beetle *Paederus* sp. (Coleoptera: Staphylinidae) as a predator of *Euxoa segetum* Schiffer Miller (Lepidoptera: Noctuidae) in India. *Indian J. entomol.*, **31**: 77-8.

Visalakshi, A., A. Jacob and M. R. G. K. Nair, 1976. Biology of *Riptortus pesdestris* F. (Coreidae: Hemiptera), a pest of cowpea. *Entomon* **1**: 139-142.

Visalakshi, A. and M. R. G. K. Nair, 1978. Biology of *Lema lacordiarei* Baly. (Coleoptera: Chrysomelidae: Criocerinae) a pest of Yam *Diascorea alata* in Kerala. *Entomon* **3**: 129-131.

Wang Haojie, R.V. Varma and Xu Tiansen, 1998. Insect Pests of Bamboos in Asia. *INBAR*, *Beijing/New Delhi*, p 200.

Weaver, N., 1966. Physiology of caste determination. *Ann. Rev. Ent.*, **11**: 79-102.

Weaving, A. J. S., 1970. Susceptibility of some bruchid beetles of store pulses to powders containing pyrethrins and piperonyl butoxide. *Pyrethrum Post*, **10**: 17-21.

Whitten, J., 1968. Metamorphic changes in insects, *Metamorphosis*, eds. W. Etkin and L. I. Gilbert, Appleton-Century-Crofts, N.Y., pp 43-105.

Wickler, W., 1968. *Mimicry in Plants and Animals* (trans. by R. D. Martin). Weidenfield and Nicolson, London, pp 1-153.

Wigglesworth, V. B., 1953. *Principles of Insect Physiology*. Methuen, London, pp 1-524.

Wigglesworth, V.B., 1972. *The Principles of Insect Physiology and Endocrinology*. Chapman & Hall. London, p 626.

Wigglesworth, V. B., 1974. *Insect Physiology*. Chapman & Hall, London, p 166.

Wood, D. L., R. M. Silverstein and M. Nakajima, 1970. *Control of Insect Behaviour by Natural Products*, Academic Press, N.Y., pp 1-345.

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