M.Sc. Final Year

Zoology, Paper V

APPLIED ENTOMOLOGY

मध्यप्रदेश भोज (मुक्त) विश्वविद्यालय – भोपाल

MADHYA PRADESH BHOJ (OPEN) UNIVERSITY - BHOPAL

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SYLLABI-BOOK MAPPING TABLE

Applied Entomology

Syllabi	Mapping in Book
Unit-I 1. Outline Classification of Insects upto Families According to Imms. 2. Pathogenic and Non pathogenic Insects, their Role in Contaminating and Causing Water Born Diseases. 3. Collection and Preservation of Insects. 4. Insects as Carriers of Plant Diseases. 5. Insects in the Service of Forensic Science. 6. Wood Boring Beetles (Life History and Control Measures)	**Unit-1:** Insects: Classification, Types, Role and Preservation **(Pages 3-77)**
Unit-II 1. Biological Control of Insect Pests. 2. Genetic Control of Insect Pests. 3. Insects Resistance to Insecticides. 4. Principles of Pesticides Residues and their Hazards in India. 5. Insecticide Appliances. 6. Insect Migration. Population Fluctuation and Factors.	**Unit-2:** Biological and Genetic Control of Insect Pests **(Pages 77-127)**
Unit-III 1. Common Insect Pests with their Life Cycles and Control Measures:- (a) Pests of Cotton (b) Pests of Sugarcane (c) Pests of Paddy (d) Pests of Stored Food Grains (e) Pests of Citrus and Mango (f) Household Insect Pests (g) Pests of Pulses. 2. Insect Pests - Management, Strategies and Tools. 3. Insects of Medicinal and Veterinary Importance.	**Unit-3:** Insect Pests **(Pages 129-216)**
Unit-IV 1. Mulberry and Nonmulberry Sericulture. 2. Apiculture 3. Lac Culture 4. Insects and Pollination. 5. Insects as Human Food for Future 6. Ecological Factors Affecting the Population and Development of Insects.	**Unit-4:** Beneficial Insects **(Pages 217-266)**

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INTRODUCTION

NOTES

Entomology is a branch of zoology which encompasses the scientific study of insects. Entomology overlaps with a cross-section of topics as diverse as molecular genetics, behavior, neuroscience, biomechanics, biochemistry, systematics, physiology, developmental biology, ecology, morphology, and paleontology. Applied entomology is a branch of entomology which deals with the study of ways to control insect pests in terrestrial Ecosystems. Applied aspects of economic entomology encompasses the harmful and beneficial impact of insects on humans and their activities. Entomology also plays an important role in studies of biodiversity and assessment of environmental quality.

There are many insects (and other arthropods) that affect human health. These arthropods include Diptera, Hemiptera, Thysanoptera, Phthiraptera, and Siphonaptera. They can parasitize, bite, sting, cause allergic reactions, and/or vector disease to humans. It can be impossible to know the full impact that insects and other arthropods have on human health. Some insect species are parasitic, and may vector diseases. Some insects perform complex ecological roles; blow-flies, for example, help consume carrion but also spread diseases. Insect pollinators are essential to the life cycle of many flowering plant species on which most organisms, including humans, are at least partly dependent. Many insects are considered ecologically beneficial as predators and a few provide direct economic benefit. Silkworms produce silk and honey bees produce honey and both have been domesticated by humans. Insects are consumed as food in 80% of the world's nations, by people in roughly 3000 ethnic groups. Insects that cause losses are termed as pests. Economic entomology is a field of entomology, which involves the study of insects that benefit or harm humans, domestic animals, and crops. Some species can cause indirect damage by spreading diseases and these are termed as vectors.

The branch of entomology deals with insects and arthropods that impact human health, is medical entomology, or public health entomology, and also veterinary entomology. Veterinary entomology is included in this category, because many animal diseases can spread and become a human health threat. Medical entomology also includes scientific research on the behavior, ecology, and epidemiology of arthropod disease vectors, and involves a tremendous outreach to the public.

Forensic entomology is the scientific study of the invasion of the succession pattern of arthropods with their developmental stages of different species found on the decomposed cadavers during legal investigations. It is the application and study of insect and other arthropod biology to criminal matters. It also involves the application of the study of arthropods, including insects, arachnids, centipedes, millipedes, and crustaceans to criminal or legal cases. It is primarily associated with death investigations; however, it may also be used to detect drugs and poisons, determine the location of an incident, and find the presence and time of the infliction of wounds.

NOTES

This book is divided into four units that attempt to give the students the basic idea of an outline classification of insects up to families, pathogenic and non-pathogenic insect, the role of insects in water borne diseases, collection and preservation of insects, role of insects in service of forensic science, wood boring beetles, biological and genetic control of insects, insects resistant to insecticides, insecticide appliances, insect migration, common insect pests and their life cycles, management strategies and tools to control insect pests, insects of medicinal and veterinary importance, mulberry and non-mulberry sericulture, apiculture, lac culture, insects and pollination, insect as human food for future and ecological factors effecting the population and development of insects. The book follows the Self-Instructional Mode or SIM format wherein each unit begins with an 'Introduction' to the topic followed by an outline of the 'Objectives'. The detailed content is then presented in a simple and structured manner interspersed with Answers to 'Check Your Progress' questions. A list of 'Key Terms', a 'Summary' and a set of 'Self-Assessment Questions and Exercises' is also provided at the end of each unit for effective recapitulation.

UNIT 1 INSECTS: CLASSIFICATION, TYPES, ROLE AND PRESERVATION

Structure

1.0 INTRODUCTION

Insects is derived from Latin that means *insectum*. Insects are pancrustacean hexapod invertebrates of the class Insecta. They are the largest group within the arthropod phylum. Insects have a chitinous exoskeleton, a three-part body, i.e., head, thorax and abdomen, three pairs of jointed legs, compound eyes and one pair of antennae. Nearly all insects hatch from eggs. Insect growth is constrained by the inelastic exoskeleton and development involves a series of molts.Adult insects typically move about by walking, flying, or sometimes swimming. Insects are the only invertebrates to have evolved flight, and all flying insects derive from one common ancestor. Insects are mostly solitary, but some, such as certain bees, ants and termites, are social and live in large, well-organized colonies. Some insects, such as earwigs, show maternal care, guarding their eggs and young. Insects can communicate with each other in a variety of ways. Male moths can sense the pheromones of female moths over great distances

The pathogens that cause disease in insects fall into four main groups: viruses, bacteria, fungi, and protozoa. Pathogens are viruses or microorganisms that cause disease. Like all other organisms, insects are susceptible to a variety of diseases caused by pathogens. Many of these pathogens cause diseases that are acute and fatal and therefore are used as models to study processes of infection and pathogenesis as well as to control populations of insects that are pests or vectors of plant and animal diseases

Insect collecting refers to the collection of insects and other arthropods for scientific study or as a hobby. Most insects are small and the majority cannot be identified without the examination of minute morphological characters, so entomologists often make and maintain insect collections. Insects are passively caught using funnels, pitfall traps, bottle traps, malaise traps, flight interception traps and other passive types of insect traps, some of which are baited with small bits of sweet foods (such as honey).

Most disease-causing viruses are carried and transmitted naturally by insects and mites, which are called vectors of the virus. Forensic entomology is the study of arthropods, especially insects, associated with crimes and other aspects of the courts and judicial system. Forensic entomology usually involves the identification of insects and other arthropods associated with human remains as an aid to determining the time and place of death.

The term woodboring beetle encompasses many species and families of beetles whose larval or adult forms eat and destroy wood, i.e., are xylophagous. Woodboring beetles most often attack dying or dead trees. In forest settings, they are important in the turnover of trees by culling weak trees, thus allowing new growth to occur. They are also important as primary decomposers of trees within forest systems, allowing for the recycling of nutrients locked away in the relatively decay-resilient woody material of trees.

In this unit, you will study about the outline classification of insects up to families, pathogenic and non-pathogenic insects, their role in contaminating and causing water borne diseases, collection and preservation of insects, insects as carrier of plants diseases, insects in service of forensic science and wood boring beetles.

1.1 OBJECTIVES

After going through this unit, you will be able to:

- Draw an outline classification of insects up to families
- Understand about pathogenic and non-pathogenic insects
- Analyze the role of insects in contaminating and causing water borne diseases
- Explain how collection and preservation of insects is done
- Discuss how insects acts as carrier of plants diseases
- Understand the role of insects in service of forensic science
- Discuss about wood boring beetles

1.2 OUTLINE CLASSIFICATION OF INSECTS UP TO FAMILIES

Arthropods are members of the Phylum Arthropoda. The word Arthropoda comes from two Greek words *arthron* and *podos*, where *arthron* means 'joint', and *podos* means 'foot', which together mean 'jointed feet'. Arthropods include the insects, arachnids, crustaceans, and others. The general characteristics of Phylum Arthropoda have the following characteristics (Refer Figure 1.1):

- Arthros means jointes and poda means appendages, hence the name of the phylum is derived from this characteristic.
- Largest phylum of the kingdom Animalia including insects, spiders, crayfish, etc.
- Body is divided into three parts namely head, thorax and abdomen.
- Antennae, simple or compound eyes, statocysts or balance organs are present.
- All the arthropods have jointed appendages which gives them a broad range of controlled and coordinated motions.
- They have organ-system level of organization.
- They are bilaterally symmetrical animals and are metamerically segmented, i.e., the segments usually groups in two or three rather distinct regions.
- They are triploblastic, i.e., having three germ layers namely-ectoderm, mesoderm and endoderm.
- They are true coelomate.
- The body being haemocoel filled with haemolymph or blood.
- The body of arthropods is protected by chitinous exoskeleton.
- A tubular alimentary canal with anterior mouth and posterior anus always present.
- Heart is dorsal to the alimentary canal with lateral openings in the abdominal region and nerve cord ventral to the alimentary canal consisting of an anterior ganglion or brain.
- Circulatory system is of open type where the only blood vessel usually being a tubular structure.
- Respiration is through several respiratory organs like gills, book gills, book lungs or tracheal system.
- Excretion takes place through Malpighian tubules
- Dioceious, i.e., sexes are separate.
- Fertilization is usually internal.
- They are oviparous or egg laying animals.
- Development may or may not include a larval stage.
- Examples: Silkworm, Lac insect, Mosquitoes, Honey bee, Locust, Crab.

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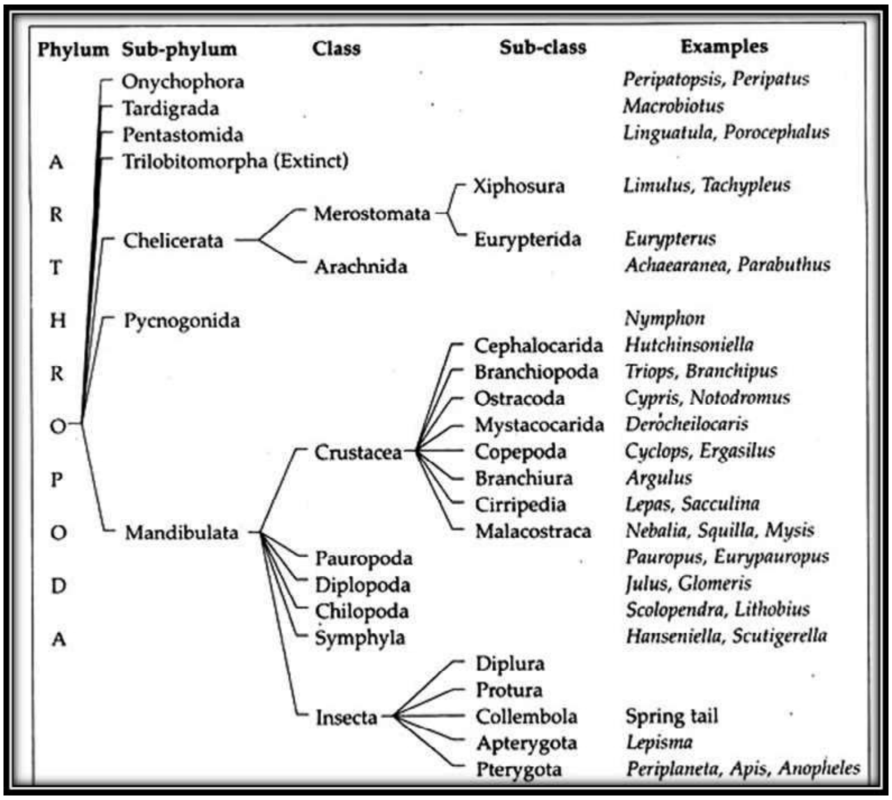

Fig. 1.1 *General Classification of Phylum Arthropoda*

General Characteristics of Class Insecta

Class Insects belongs to Phylum Arthropoda. The general characteristics of phylum Arthropoda are as follows (Refer Figure 1.2):

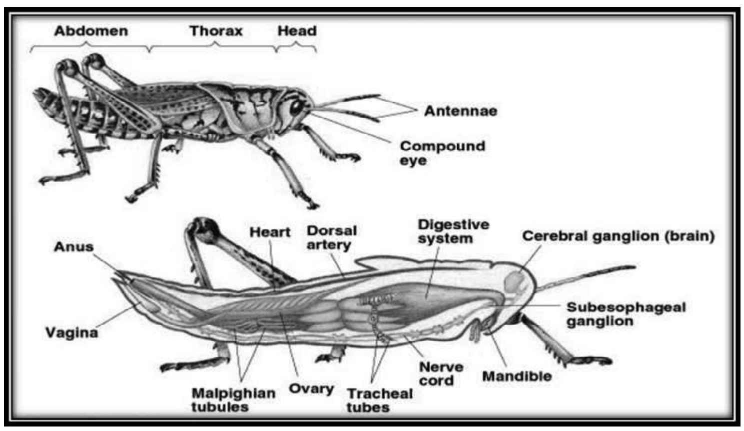

Fig. 1.2 *General Body Plan of an Insect*

Body of Insect

The body is divided into three distinct regions: Head, Thorax and Abdomen

(a) Head

Head of insects contains the following parts:

- One pair of antennae:
  - The antennae are usually used as tactile organs (organs pertaining to the sense of touch).
  - They can also be used as olfactory organs (organs of smell).
- Eyes:
  - Most insects possess one pair of compound eyes and sometimes some simple eyes called 'ocelli'.
- Mouthparts:
  - There is a big variety in types of mouthparts; biting, sucking, stinging, licking, etc.

(b) Thorax:

Thoracic region of insects contains the following parts:

- Three pairs of legs.
- The thorax has three segments.
- These are known as pro-thorax, meso-thorax and meta-thorax.
- Each segment has one pair of legs.
- The different parts of the leg are called coxa, trochanter, femur, tibia, and tarsus.
- Some insects are legless, or have fewer than 6 legs.
- Some larvae have leg-like appendages on the abdomen.
- Often one or two pairs of wings.
- The wings are borne by the second and/or third of the thoracic segments.

Note: Some insects are wingless.

(c) Abdomen:

- The gonopore (genital opening) is at the posterior end of the abdomen.
- No appendages are used for moving on the abdomen of adults (except in a few primitive insects).
- Sometimes there are some appendages at the end of the abdomen.

  The Figure 1.3 below illustrates classification of insects.

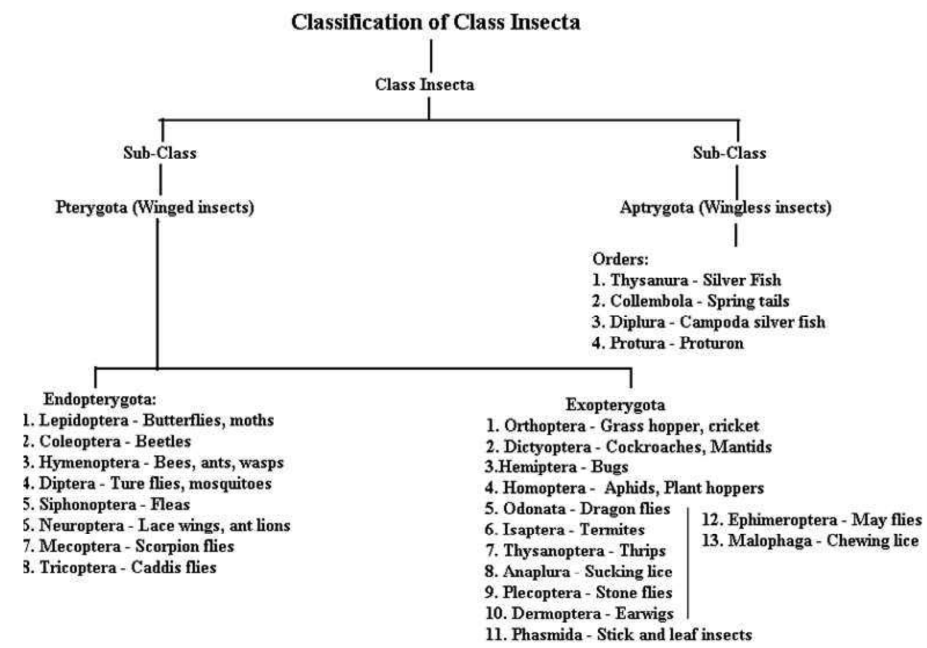

Fig. 1.3 *Classification of Insect*

General Characteristics of Subclass Apterygota

- Subclass: Apterygota (Ametabola).
- Primitively wingless insects, without metamorphosis.
- The head is prognathous.
- Mandible is attached into a specific position of head capsule.
- Abdominal appendages might be present.
- One pair or more than one pair of appendages are present in front of genital opening.
- Ectognathous mouthparts, with mandibles connected at one point.
- There is no metamorphosis as nymphs resemble adults.
- The subclass has four orders.

General Characteristics of Subclass Pterygota

- Subclass: Pterygota (Metabola).
- Winged or secondarily wingless insects, with prognathous or hypognathous head.
- Mandible is attached into two specific position of head capsule.
- Metamorphosis either insufficient without a pupal phase (incomplete metamorphosis) or total with a pupal stage (complete metamorphosis).
- Sexually matured adults do not undergo moulting.
- No appendage are present in front of genital opening.
- This subclass is divided into two superorders or divisions, specifically, Exopterygota and Endopterygota.

General Characteristics of Division Exopterygota

- Insects in this group undergo a simple or incomplete metamorphosis called Hemimetabola.
- The life cycle includes just three stages – egg, nymph, and adult.
- During the nymph stage, gradual change occurs until the nymph resembles the adult.
- Only the adult stage has functional wings.
- Young generalized as nymph.
- Pupal instar is absent or rare.
- In molting from the egg, via the nymphal stages to an adult, there is a progressive change in the external look.
- The late nymphal phases currently show the advancement of wing pads.
- But just in the last molt, operational wings are developed.
- The nymphs usually have the very same feeding habits as adults.

General Characteristics of Division Endopterygota

- In the division endopterygota, there is a complete metamorphosis that is called as holometabola comprising of four developmental stages namely: egg, larva, pupa and adult.
- The pupal stage is inactive, i.e., a resting period.
- In these insects, the external (and internal) changes throughout life are the greatest.
- The eggs hatch into larvae.
- Larval stages feed actively during the different instars.
- The larvae might or may not have legs.
- The advancement of wings is not noticeable during the larval phases.
- Larvae undergo molting to form different instars. After numerous molts, a pupa is formed.
- A pupa is a non-active phase, non-feeding and non-mobile phase.
- In some cases, the pupa is protected by a cocoon of silk, or it is present in an earthen cell in the soil.
- However, during this pupal phase a large number of modifications take place internally.
- After the pupal phase, an extremely active winged adult appears.
- Wings are developed from the internal portion of the body.
- Typically, the larvae and the adults live in different kinds of environments and utilize different kinds of food.
- When the adult emerges from the pupal stage, it has functional wings.
- Immature insects externally differ with adults.

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Table 1.1 below illustrates the comparison between division exopterygota and endopterygota.

Table 1.1 *Comparison between Division Exopterygota and Endopterygota*

Exopterygota	Endopterygota
Metamorphosis is incomplete or simple that is called as hemimetabola (3 stages of development like egg, nymph and adult are present).	Metamorphosis is complete or complex that is called as holometabola insect (4 stages of development like egg, larva, pupa and adult are present).
Wings developed from external part of the body as wing buds.	Wings developed internally from the body.
Immature insects are similar with adults.	Immature insects differ from that of mature adult.
Young are commonly known as nymph.	Young are commonly known as larva.
Pupal instar are absent or rare.	Always accompanied by larval and pupal instar.

Twenty Nine Orders of Insects

Twenty nine orders of insects are as follows (Refer Figure 1.4):

1. Sub Class: Apterygota

Order 1: Thysanura, for example Bristle tails, Silverfish.

Order 2: Diplura, for example two pronged Bristle tails.

Order 3: Protura, for example Proturans.

Order 4: Collembola, for example Spring tails.

2. Subclass: Pterygota

I. Division: Exopterygota

Order 5: Ephemeroptera, for example Mayflies.

Order 6: Odonata, for example Dragonflies, Damselflies.

Order 7: Plecoptera, for example Stoneflies.

Order 8: Orthoptera, for example Crickets, Grasshoppers and Locusts.

Order 9: Phasmida, for example Stick insects, Leaf insects.

Order 10: Dermaptera, for example Earwigs.

Order 11: Embioptera, for example Web-spinners.

Order 12: Dictyoptera, for example Cockroaches, Mantids.

Order 13: Isoptera, for example Termites.

Order 14: Zoraptera, for example Zorapterans.

Order 15: Psocoptera, for example Booklice.

Order 16: Mallophaga, for example Biting lice, Bird lice.

Order 17: Siphunculata, for example Sucking lice.

Order 18: Hemiptera, for example True bugs.

Order 19: Homoptera, for example Leafhoppers, Aphids, Scale insects, Cicadas.

Order 20: Thysanoptera, for example Thrips.

II. Division: Endopterygota

Order 21: Neuroptera, for example Lacewings, Antlions.

Order 22: Coleoptera, for example Beetles and Weevils.

Order 23: Strepsiptera, for example Stylopids.

Order 24: Mecoptera, for example Scorpion flies.

Order 25: Siphonaptera, for example Fleas.

Order 26; Diptera, for example True flies.

Order 27: Lepidoptera, for example Butterflies, Moths.

Order 28: Trichoptera, for example Caddis flies.

Order 29: Hymenoptera, for example Ants, Bees, Wasps and Sawflies.

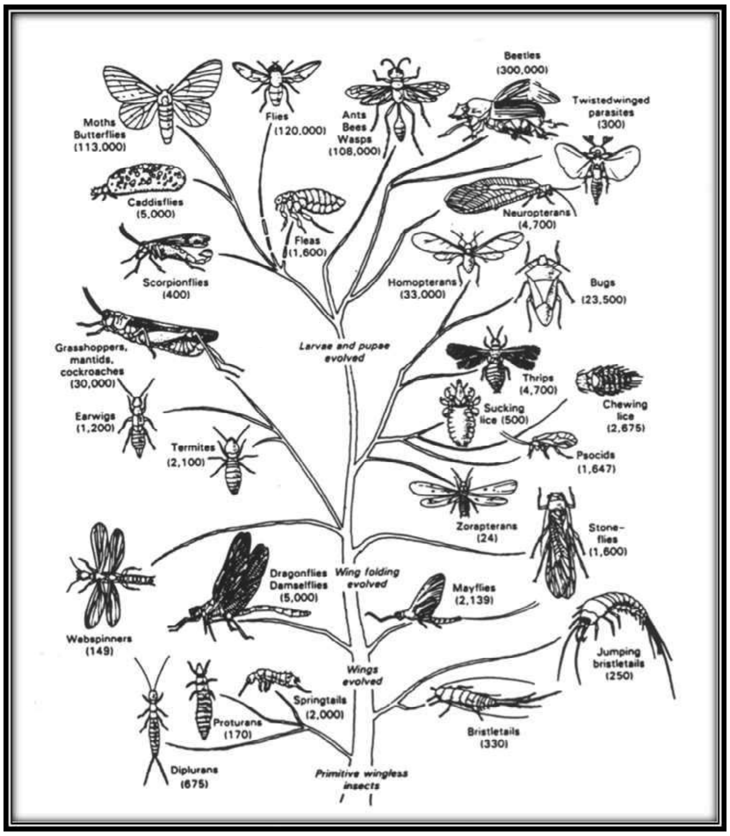

Fig. 1.4 *Different Order of Insects*

Twenty Nine Orders of Insects

Familiarity with the twenty-nine insect orders is the key to identifying and understanding insects. Here are insect orders beginning with the most primitive wingless insects, and ending with the insect groups that have undergone the greatest evolutionary change. Most insect order names end in *ptera*, which comes from the Greek word *pteron*, meaning wing.

1. Order: Thysanura

The silverfish and firebrats are found in the order Thysanura. They are wingless insects often found in people's attics, and have a lifespan of several years. There are about 600 species worldwide. There are only 4 families of silverfish found worldwide namely: Lepidotrichidae, Nicoletiidae, Lepismatidae, Maindroniidae.

2. Order: Diplura

Diplurans are the most primitive insect species, with no eyes or wings. They have the unusual ability among insects to regenerate body parts. There are over 400 members of the order Diplura in the world.

3. Order: Protura

Another very primitive group, the proturans have no eyes, no antennae, and no wings. They are uncommon, with perhaps less than 100 species known.

4. Order: Collembola

The order Collembola includes the springtails, primitive insects without wings. There are approximately 2,000 species of Collembola worldwide.

5. Order: Ephemeroptera

The mayflies of order Ephemeroptera are short-lived, and undergo incomplete metamorphosis. The larvae are aquatic, feeding on algae and other plant life. Entomologists have described about 2,100 species worldwide. Families Baetidae and Leptophlebiidae belong to order Ephemeroptera.

6. Order: **Odonata**

The order Odonata includes dragonflies and damselflies, which undergo incomplete metamorphosis. They are predators of other insects, even in their immature stage. There are about 5,000 species in the order Odonata. Families belonging to the order Odonata are Aeshnidae, Coenagrionidae, Corduliidae, Lestidae, Libellulidae, Calopterygidae, Cordulegastridae and Gomphidae.

7. Order: Plecoptera

The stoneflies of order Plecoptera are aquatic and undergo incomplete metamorphosis. The nymphs live under rocks in well flowing streams. Adults are usually seen on the ground along stream and river banks. There are roughly 3,000 species in this group. Families belonging to the order Plecoptera are Capniidae, Leuctridae, Nemouridae, Perlidae, Taeniopterygidae and Chloroperlidae.

8. Order: Grylloblatodea

Sometimes referred to as 'living fossils', the insects of the order Grylloblatodea have changed little from their ancient ancestors. This order is the smallest of all the insect orders, with perhaps only 25 known species living today. Grylloblatodea live at elevations above 1500 ft., and are commonly named ice bugs or rock crawlers.

9. Order: Orthoptera

These are familiar insects (grasshoppers, locusts, katydids, and crickets) and one of the largest orders of herbivorous insects. Many species in the order Orthoptera can produce and detect sounds. Approximately 20,000 species exist in this group.

Families belonging to the order Orthoptera are Acrididae, Meconematidae, Tetrigidae and Tettigoniidae.

10. Order: Phasmida

The order Phasmida are masters of camouflage, the stick and leaf insects. They undergo incomplete metamorphosis and feed on leaves. There are some 3,000 insects in this group, but only a small fraction of this number is leaf insects. Stick insects are the longest insects in the world.

11. Order: Dermaptera

This order contains the earwigs, an easily recognized insect that often has pincers at the end of the abdomen. Many earwigs are scavengers, eating both plant and animal matter. The order Dermaptera includes less than 2,000 species. Order Dermaptera include the family Forficulidae.

12. Order: Embioptera

The order Embioptera is another ancient order with few species, perhaps only 200 worldwide. The web spinners have silk glands in their front legs and weave nests under leaf litter and in tunnels where they live. Webspinners live in tropical or subtropical climates.

13. Order: Dictyoptera

The order Dictyoptera includes roaches and mantids. Both groups have long, segmented antennae and leathery forewings held tightly against their backs. They undergo incomplete metamorphosis. Worldwide, there approximately 6,000 species in this order, most living in tropical regions.

14. Order: Isoptera

Termites feed on wood and are important decomposers in forest ecosystems. They also feed on wood products and are thought of as pests for the destruction they cause to man-made structures. There are between 2,000 and 3,000 species in this order.

15. Order: Zoraptera

Little is known about the angel insects, which belong to the order Zoraptera. Though they are grouped with winged insects, many are actually wingless. Members of this group are blind, small, and often found in decaying wood. There are only about 30 described species worldwide.

16. Order: Psocoptera

Bark lice forage on algae, lichen, and fungus in moist, dark places. Booklice frequent human dwellings, where they feed on book paste and grains. They undergo incomplete metamorphosis. Entomologists have named about 3,200 species in the order Psocoptera. Families that belong to the order Psocoptera are Caeciliusidae, Epipsocidae, Psocidae, Stenopsocidae, Trogiidae, Ectopsocidae and Philotarsidae.

17. Order: Mallophaga

Biting lice are ectoparasites that feed on birds and some mammals. There are an estimated 3,000 species in the order Mallophaga, all of which undergo incomplete metamorphosis.

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18. Order: Siphunculata

The order Siphunculata are the sucking lice, which feed on the fresh blood of mammals. Their mouthparts are adapted for sucking or siphoning blood. There are only about 500 species of sucking lice.

19. Order: Hemiptera

Most people use the term 'bugs' to mean insects; an entomologist uses the term to refer to the order Hemiptera. The Hemiptera are the true bugs, and include cicadas, aphids, and spittlebugs, and others. This is a large group of over 70,000 species worldwide. Some of the Families belonging to order Hemiptera are Acanthosomatidae, Aphrophoridae, Cercopidae, Cicadellidae, Delphacidae, Gerridae, Hydrometridae, Lygaeidae, Membracidae, Miridae, Nabidae, Pentatomidae, Psyllidae, Reduviidae, Rhopalidae, Saldidae, Tingidae and Veliidae.

20. Order: Thysanoptera

The thrips of order Thysanoptera are small insects that feed on plant tissue. Many are considered agricultural pests for this reason. Some thrips prey on other small insects as well. This order contains about 5,000 species.

21. Order: Neuroptera

Commonly called the order of lacewings, this group actually includes a variety of other insects, too: dobsonflies, owlflies, mantidflies, antlions, snakeflies, and alderflies. Insects in the order Neuroptera undergo complete metamorphosis. Worldwide, there are over 5,500 species in this group. Families Chrysopidae, Coniopterygidae, Hemerobiidae, Osmylidae belongs to the order Neuroptera.

22. Order: Mecoptera

This order includes the scorpionflies, which live in moist, wooded habitats. Scorpionflies are omnivorous in both their larval and adult forms. The larva are caterpillar-like. There are less than 500 described species in the order Mecoptera. Family Panorpidae belongs to the order Mecoptera.

23. Order: Siphonaptera

Pet lovers fear insects in the order Siphonaptera - the fleas. Fleas are blood-sucking ectoparasites that feed on mammals, and rarely, birds. There are well over 2,000 species of fleas in the world.

24. Order: Coleoptera

This group, the beetles and weevils, is the largest order in the insect world, with over 300,000 distinct species known. The order Coleoptera includes well-known families: june beetles, lady beetles, click beetles, and fireflies. All have hardened forewings that fold over the abdomen to protect the delicate hindwings used for flight. Some of the Families that belong to order Coleoptera are Anobiidae, Cetoniidae, Elateridae, Leiodidae, Dascillidae, Dasytidae, Dermestidae, Derodontidae, Geotrupidae, Lycidae, Mycetophagidae, Nitidulidae, Oedemeridae, Phalacridae, Pyrochroidae, Rhynchitidae, Staphylinidae and Throscidae.

25. Order: Strepsiptera

Insects in this group are parasites of other insects, particularly bees, grasshoppers, and the true bugs. The immature Strepsiptera lies in wait on a flower and quickly burrows into any host insect that comes along. Strepsiptera undergo complete metamorphosis and pupate within the host insect's body.

26. Order: Diptera

Diptera is one of the largest orders, with nearly 100,000 insects named to the order. These are the true flies, mosquitoes, and gnats. Insects in this group have modified hindwings which are used for balance during flight. The forewings function as the propellers for flying. Some of the Families that belong to order Diptera are Agromyzidae, Ceratopogonidae, Drosophilidae, Dryomyzidae, Empididae, Fanniidae, Heleomyzidae, Hippoboscidae, Lonchopteridae, Megamerinidae, Opomyzidae, Psychodidae, Ptychopteridae, Syrphidae, Tabanidae, Tipulidae and Ulidiidae.

27. Order: Lepidoptera

The butterflies and moths of the order Lepidoptera comprise the second largest group in the class Insecta. These well-known insects have scaly wings with interesting colors and patterns. You can often identify an insect in this order just by the wing shape and colour. Some Families that belong to the order Lepidoptera are Adelidae, Alucitidae, Batrachedridae, Bucculatricidae, Chimabachidae, Choreutidae, Drepanidae, Erebidae, Momphidae, Nepticulidae, Oecophoridae, Papilionidae, Pieridae, Plutellidae, Sesiidae, Tortricidae, Yponomeutidae and Zygaenidae

28. Order: Trichoptera

Caddisflies are nocturnal as adults and aquatic when immature. The caddisfly adults have silky hairs on their wings and body, which is key to identifying a Trichoptera member. The larvae spin traps for prey with silk. They also make cases from the silk and other materials that they carry and use for protection. Some of the Families that belong to the order Trichoptera are Apataniidae, Goeridae, Leptoceridae, Phryganeidae, Rhyacophilidae, Hydropsychidae, Psychomyiidae and Glossosomatidae.

29. Order: Hymenoptera

The order Hymenoptera includes many of the most common insects - ants, bees, and wasps. The larvae of some wasps cause trees to form galls, which then provides food for the immature wasps. Other wasps are parasitic, living in caterpillars, beetles, or even aphids. This is the third-largest insect order with just over 100,000 species. Some of the Families that belong to order Hymenoptera are Argidae, Cynipidae, Eurytomidae, Platygastridae, Siricidae, Formicidae, Vespida, Pompilidae, Torymidae, Chrysididae, Eulophidae, Leucospidae, Sapygidaeandn and Figitidae.

The Figure 1.5 below illustrates the generalized body plan of different insect orders.

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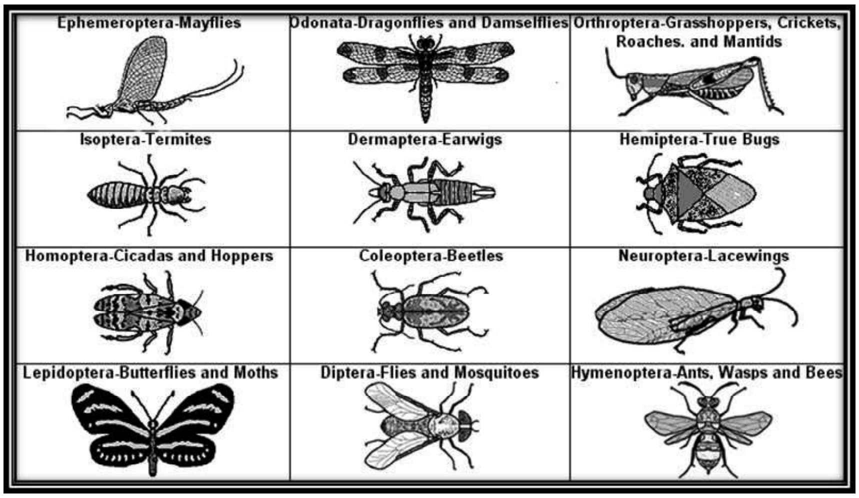

Fig. 1.5 *Generalized Body Plan of Different Insect Orders*

Check Your Progress

1. What are arthropods?
2. What does the head of insect consists of?
3. Name five orders of insects.

1.3 PATHOGENIC AND NON-PATHOGENIC INSECTS, THEIR ROLE IN CONTAMINATING AND CAUSING WATER BORNE DISEASES

The role of pathogenic and non-pathogenic insects in contaminating and causing water borne diseases are as follows:

1.3.1 Pathogenic Insects

Pathogenic insects are those insects that acts as an intermediate or alternative host for a pathogenic organism like bacteria, virus or fungi and transmits them to a susceptible host. In parasitology, such organisms are known as vector. A vector is referred to as an organism that acts as an intermediate or alternative host for a pathogenic organism and transmits them to a susceptible host. Thus, vectors are nothing but vehicles by which the parasites are transmitted from one host to another, i.e., the animal that acts as a carrier of disease producing germs (parasites) for transmission of disease from one host to another host.

These vectors are sometimes also known as biological vectors. Biological vectors are those organisms (invertebrate animals like insects) in which the disease agents or disease-causing microorganisms increase their numbers either by multiplication or transformation. When the disease-agent (parasite) undergoes multiplication or some developmental changes in vector host then such transmission is known as **biological transmission**. The organisms or animals which are involved in spreading or transmitting the disease are known as vectors or carriers. For example female Anopheles mosquito acts as vector of malarial parasite (Plasmodium sp.). There are three modes of transmission of diseases by biological vectors namely: Propagative transmission, Cyclopropagative transmission and Cyclodevelopmental transmission.

- **Propagative Transmission:** When the disease-causing agent or parasite undergoes multiplication within the body of biological vector however no cyclical change is observed, then the transmission is called as propagative transmission. For example Plague *bacilli* in rat fleas.
- **Cyclopropagative Transmission:** In cyclopropagative transmission, the parasite undergoes multiplication in the body of the vector and at the same time cyclical change is also observed. For example *Plasmodium* (malarial parasite) in female Anopheles mosquito.
- **Cyclodevelopmental Transmission:** When the disease-causing agent (like bacteria, fungi, virus) or parasite undergoes no multiplication in the body of vector however they do undergo cyclical changes. For example Guinea- worm embryo in Cyclops and filarial parasite (Wuchereria) in Culex mosquito.

Some of the examples of pathogenic insects are as follows:

1. *Aedes aegyptii* and *Aedes albopictus*

Aedes is a genus of mosquitoes originally found in tropical and subtropical zones, but now found on all continents except Antarctica. Some species have been spread by human activity: *Aedes albopictus*, a particularly invasive species, was recently spread to the New World, including the United States, by the used-tire trade.

Aedes mosquitoes are visually distinctive because they have noticeable black and white markings on their bodies and legs. Unlike most other mosquitoes, they are active and bite only during the daytime. The peak biting periods are early in the morning and in the evening before dusk (Refer Figure 1.6).

Aedes aegypti, the yellow fever mosquito, is a mosquito that can transmit dengue fever, chikungunya, Zika fever, Mayaro, yellow fever viruses, as well as other disease-causing agents. The mosquito can be recognized by white markings on its legs and a marking in the form of a lyre on the upper surface of its thorax. This mosquito originated in Africa, but is now found in tropical, subtropical and temperate regions throughout the world. It takes approximately 7-10 days for an egg to develop into an adult mosquito. Aedes can be detected and monitored by ovitraps.

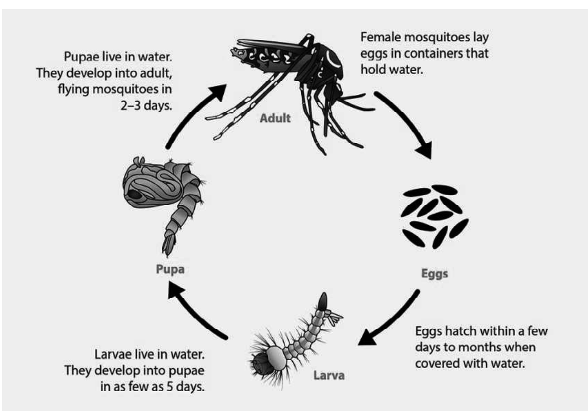

Fig. 1.6 *Life Stages of Aedes aegypti and Aedes albopictus*

Life stages of *Aedes aegypti* and *Aedes albopictus*

Life stages of *Aedes aegypti* and *Aedes albopictus* are discussed below (Refer Figure 1.7):

Eggs

- Adult, female mosquitoes lay eggs on the inner walls of containers with water present above the waterline.
- The newly laid eggs stick to container walls like glue.
- They can survive drying out for up to 8 months.
- Mosquitoes usually requires only a small amount of water to lay eggs.
- Small containers like bowls, cups, fountains, tires, barrels, vases, and any other container holding water can become a breeding ground for mosquitoes.

Larvae

- Larvae stays in the water.
- Larvae hatch from mosquito eggs.
- This generally occurs when water (from rain or a sprinkler) covers the eggs.
- Larvae can be seen in the water.
- Larvae are very active and are usually called as 'wigglers'.

Pupae

- Pupae live in the water.
- An adult mosquito emerges from the pupa and flies away.

Adult

- Adult female mosquitoes bite people and animals.
- Mosquitoes require blood to get nutrition for producing eggs.
- After feeding, female mosquitoes look for water sources to lay eggs.
- *Aedes aegypti* and *Aedes albopictus* do not fly for long distances. In its entire lifetime, these mosquitoes will only fly within a few blocks.
- *Aedes aegypti* mosquitoes prefer to stay near and bite people.
- As *Aedes albopictus* mosquitoes bite people as well as animals, they can live in or near homes or in neighbouring woods.
- *Aedes aegypti* mosquitoes stays indoors as well as outdoors, while *Aedes albopictus* live in outdoors.

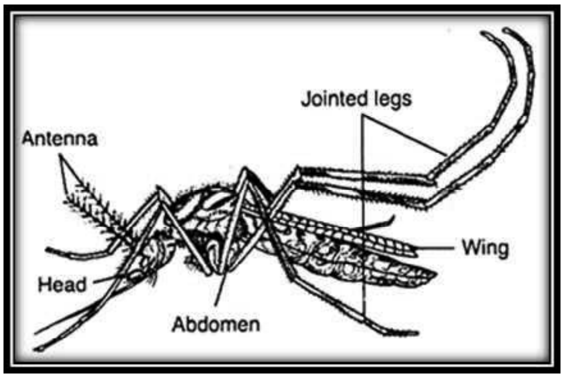

Fig. 1.7 *External Morphology of Aedes aegyptii*

2. *Anopheles* Mosquito

There are approximately 3,500 species of mosquitoes grouped into 41 genera. Female *Anopheles* mosquito is responsible for transmitting Malaria to humans (Refer Figure 1.8). Male mosquitoes do not bite so cannot transmit malaria or other diseases. Out of the approximately 430 *Anopheles* species, only 30-40 are capable of transmitting malaria, i.e., are vectors to humans. The other species either bite humans rarely or cannot withstand development of malaria parasites. It requires blood as a source of nutrition for producing eggs and hence these blood meals are the link between the human and the mosquito hosts in the parasite life cycle. The successful development of the malaria parasite in the mosquito from the gametocyte stage to the sporozoite stage depends on a lot of factors. The two most important factors are ambient temperature and humidity (higher temperatures accelerate the growth of parasite in the mosquito) and whether the *Anopheles* survives long enough to allow the parasite to complete its cycle in the mosquito host (sporogonic or extrinsic cycle, having a duration of 9 to 18 days). In contrast to the human host, the mosquito host does not suffer markedly from the presence of the parasites.

Anopheles mosquitoes have a worldwide distribution. The only exception being Antarctica. Malaria is transmitted via different *Anopheles* species in different geographic regions. Within those geographic regions, different environments support a different species. Anopheles mosquitoes that can spread malaria are found not only in malaria-endemic areas, but also in areas where malaria has been eliminated. Hence, areas from where malaria has been eradicated previously are at risk of re-introduction of the disease.

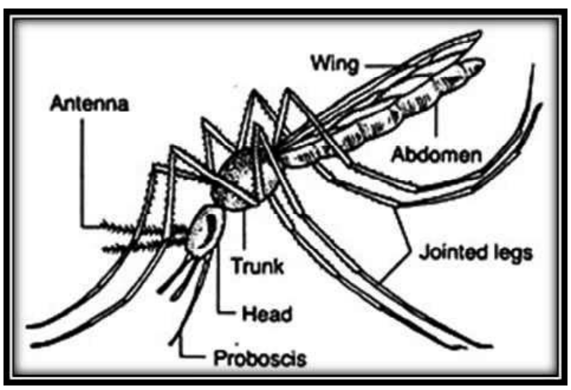

Fig. 1.8 *Adult Female Anopheles Mosquito*

The entire life cycle of *Anopheles* mosquitoes can be divided into four stages namely egg, larva, pupa, and adult. The first three stages are aquatic and last 7-14 days, depending on the species and the ambient temperature. The biting female *Anopheles* mosquito may carry malaria. The adult females are generally short-lived, with only a small proportion living long enough (more than 10 days in tropical regions) to transmit malaria.

Eggs

Adult Female *Anopheles* mosquito lays approximately 50-200 eggs per oviposition. Eggs are either laid singly or directly on water and thus are unique in having floats on either side. The laid eggs are not resistant to unfavourable environmental conditions like drying and hatch within 2-3 days, even though hatching may take up to 2-3 weeks in colder regions.

Larvae

The larvae of *Anopheles* mosquito comprise of a well-developed head with mouth brushes which is used for feeding, a large thorax, as well as a segmented abdomen. Mosquito larvae lack legs. In contrast to other mosquitos' species, the larvae of *Anopheles* mosquito lack a respiratory siphon and for this reason position themselves so that their body is parallel to the surface of the water. Larvae breathe via spiracles which are located on the 8th abdominal segment and hence must come to the surface frequently. The larvae of *Anopheles* mosquito spend most of its time feeding on algae, bacteria, as well as other microscopic organisms present in the surface microlayer. Larvae of *Anopheles* mosquito do so by rotating their head 180 degrees and feeding from below the microlayer. Larvae dive below the surface only when disturbed. Larvae swim either by jerky movements of the entire body or through propulsion with the mouth brushes. Larvae develop through 4 stages, or instars, after which they metamorphose into other form known as pupae. At the end of each instar, the larvae molt, shedding their exoskeleton, or skin, to allow for further growth.

The larvae of *Anopheles* mosquito occur in a wide range of habitats and majority of the species prefer clean, unpolluted water for reproduction. Larvae of *Anopheles* mosquitoes have been found in fresh or salt water marshes, mangrove swamps, rice fields, grassy ditches, the edges of streams and rivers, as well as small and temporary rain pools.

Pupae

The pupa of the *Anopheles* mosquito is comma-shaped when viewed from the sideways. Pupae represents the transitional stage between larva and adult. The pupae of the Anopheles mosquito do not feed; however, it undergoes essential metamorphosis. The head and thorax are merged to form a specialized structure known as cephalothorax with the abdomen curving around underneath. Pupa breathe with the help of a pair of respiratory trumpets present on the cephalothorax. After a few days as a pupa, the dorsal surface of the cephalothorax splits and the adult mosquito emerges onto the surface of the water.

The duration from egg to adult varies considerably among species and is strongly influenced by ambient temperature. The time period of entire life cycle is 7-14 days.

Adults

The body of the adult *Anopheles* mosquito is divided into three regions namely head, thorax and abdomen. The head is a specialized structure used for acquiring sensory information as well as for feeding. The head region comprises of the eyes as well as a pair of long, many-segmented antennae. The antennae are essential for detecting host odours and odours of aquatic larval habitats where females lay eggs. The head also has an elongate, forward-projecting proboscis which is used for feeding, and two sensory palps.

The thorax region is specialized for carrying the locomotion. Three pairs of legs as well as a single pair of wings are attached to the thorax region of the insect.

The abdomen is specialized for carrying two processes efficiently namely food digestion and egg development. This segmented body part enlarges significantly whenever a female takes a blood meal. On digestion, the blood provides the nutrition or act as a source of protein for the production of eggs, which slowly fill the abdomen.

Anopheles mosquitoes can be easily distinguished from other species of mosquitoes by the palps, which are as long as the proboscis, and also by the presence of separate blocks of black as well as white scales on the wings. Further, Adult *Anopheles* mosquito can also be identified by the presence of typical resting position: adult males as well females of genus *Anopheles* rest with their abdomens sticking up in the air rather than parallel to the surface on which they are resting.

Adult mosquitoes generally mate within a few days after emerging from the pupal stage. In few species, the males form large swarms, generally around dusk, and the females fly into the swarms to mate. However, the mating habitats of several mosquito species is unknown till date.

The life span of adult males is approximately a week. It feeds on nectar as well as other sources of sugar. Adult females will also feed on sugar sources for getting energy however it generally requires a blood meal for the development of eggs. After obtaining a full blood meal, the female will rest for a few days while the blood is digested and eggs are developed. The entire process of digestion as well as development of eggs depends on the temperature, however, it usually takes around 2-3 days in tropical conditions. Once the eggs are fully developed, the female lays them then look for another blood meal in order to sustain another batch of eggs.

This cycle keeps on repeating itself until the adult female dies. Adult females can survive up to a month (or longer in captivity) however majority of them do not live longer than 1-2 weeks in nature (Refer Figure 1.9). The chances of survival of adult females depends upon lot of factors like favourable environmental conditions, availability of host for obtaining blood meal, host defense mechanism, etc.

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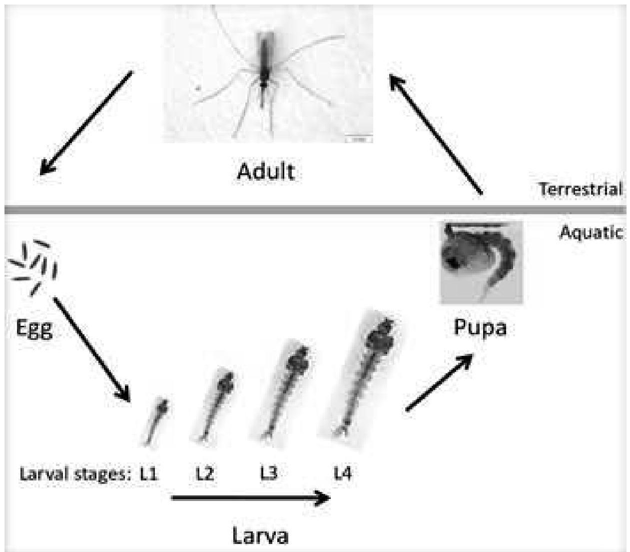

Fig. 1.9 *Life Cycle of Anopheles Species*

3. *Phlebotomus sp.*

Insects belonging to genus *Phlebotomus* are tiny insects, measuring approximately 1.5-3.5 mm in length, having a hairy appearance, large black eyes and long, stilt-like legs. Sand flies can be differentiated from other small flies by their wings. Wings are hairy in structure and extend at an angle of 40° over the body when the fly is at rest or blood-feeding. Sand flies (*Phlebotominae*) comprises of piercing mouthparts which are capable of taking blood. The phlebotomines tend to have an elongated as well as more delicate structure, as compared to the squatter and stronger appearance of the other psychodid flies.

Phlebotomus sp. are primarily found in warm, humid, tropical climates as well as semi-desert vegetation habitats, even though, a few species have also been reported from temperate zones. Phlebotomus species are able to colonise rural, periurban as well as urban areas. They need a humid microclimate for the development of eggs as compared to larva which require a cool, moist habitat with decaying debris for its development. Adult *Phlebotomus* species usually inhabit rock crevices, caves, as well as rodent burrows, and in peridomestic settings rest in cool, dark and humid corners of animal shelters or human dwellings.

Male as well as female insects belonging to genus *Phlebotomus* feed on plant juices and other sugary secretions. However, females required blood-feed to produce eggs. Adult female sand flies feed on a wide variety of vertebrate hosts like humans, livestock, dogs, urban as well as wild rodents, reptiles, amphibians, and birds. Insects belonging to genus *Phlebotomus* are opportunistic and feed on those animals to which they have easiest access, as the same species collected from in nature and thus different biotopes usually display different feeding patterns. The mouthparts are well developed and well-designed to probe exposed skin, leading to the formation of a pool of blood from which they feed. The saliva of adult *Phlebotomus* species contains pharmacologically active components that aid in the process of feeding. The feeding activity of the insects is influenced by several factors like temperature, humidity as well as air movement. Majority of the species belonging to genus *Phlebotomus* prefer to feed at dusk time as well as during the night, when the temperature falls and humidity rises, even though, daytime biting can occur indoors in darkened rooms or among shaded vegetation/trees, particularly, if disturbed by human activity.

As soon as after their emergence, adult flies mates. Adult males look for females at resting sites or on vertebrate hosts, with the help of pheromones. The fecundity of the female is approximately 30-70 eggs during a single gonotrophic cycle. The freshly laid eggs are deposited in cracks and crevices in the ground as well as in buildings, animal burrows or sometimes among tree roots. The eggs need a microhabitat with high humidity for its survival, but are not laid in water. Usually, one blood meal if more than sufficient to produce one batch of eggs.

The life cycle of *Phlebotomus* species can be divided into four stages namely egg, larva, pupa and adult. Eggs hatch approximately after a period of 4-20 days, even though, it is likely to be delayed in cooler weather. The development of larva includes four instars, and is completed within a period of 20-30 days depending on factors like environmental conditions, presence of nutrients, species, temperature, etc. Unfavourable environmental conditions like heat, cold, pressure, drought, etc. can cause larvae to undergo diapause, extending development time for months. Larvae are primarily scavengers, feeding on organic matter (for example- fungi, decaying leaves, animal faeces as well as other decomposing arthropods). The pupal stage lasts approximately for 6-13 days before the adult sand flies emerge (Refer Figure 1.10).

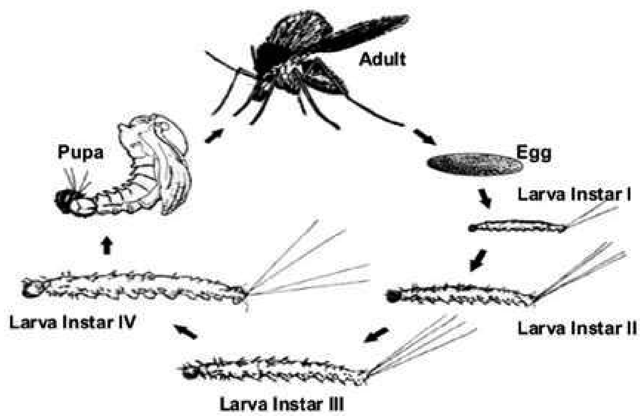

Fig. 1.10 *Life Cycle of Phlebotomus Species*

The population density of the sand flies varies on the basis of environmental conditions like local climate, with significant seasonal changes in temperature as well as precipitation leading to fluctuations in sand fly numbers, i.e., the number of sand flies are at minimal during the coldest and/or driest seasons of the year. Further, in tropical regions, few species are commonly found throughout the year, on the contrary, other species exhibit marked changes in relation to both wet as well as dry seasons. Adult sand flies are only found during the summer season in temperate regions. Further, different species of sand fly have different seasonal activity periods and daily peaks of biting activity. Adult sand flies are weak fliers and hence more than often they disperse no more than a few hundred metres from their breeding sites. Majority of the species belonging to genus *Phlebotomus* fly horizontally

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near ground level. In temperate as well as arid regions, sand flies may overwinter as diapausing mature larvae.

4. *Glossina Palpalis*

Glossina Palpalis (Tsetse fly) flies belongs to genus *Glossina* are obligate haematophagous insects, i.e., both male as well as female flies survive purely on blood diet. Infected flies are capable of transmitting the single-celled protozoan parasite known as *Trypanosoma brucei* which causes African sleeping sickness (or African Trypanosomiasis) in humans and Nagana in cattle. Early symptoms of the disease caused are very similar to flu (like fever, joint pains as well as headaches), however, these symptoms rapidly progress to severe swelling of the lymph nodes as the parasites multiply in the blood. If left untreated, the disease will ultimately progress to produce the neurological disorders that give the disease its name, with patients having disrupted sleep patterns, reduced coordination and becoming confused. Once it reaches this stage the neurological damage is usually irreversible and if allowed to continue its progression is almost always fatal.

The life cycle of the tsetse flies is quite different when compared to other insects. Most invertebrates have a reproductive strategy which involves producing large numbers of offspring to offset losses which occur due to predation as well as to enable quick increases in population whenever possible. On the other hand, Tsetse flies, only produces one larva at a time and incubate each within their bodies until the larva is fully developed. Within its lifetime, each female is only capable of raising a handful of offspring.

Courtship and Mating

Females are very receptive to mating almost immediately after their emergence from the pupa. There is no courtship period involved. The male simply lands on the female's back. Copulation usually last for 1-2 hours, during which the male deposits a ball of sperm at the entrance to the spermathecal ducts. From there the sperm swim up towards the spermatheca (an organ for holding sperms), where they remain in a viable state for the remainder of the female's life. The female mate only once in her lifetime and does not need to mate again. Approximately, 7-9 days after the emergence, a single fertilized egg is implanted in the female's uterus. The embryo develops inside the female's body, hatches, and the larva completes its full growth cycle in the uterus (Refer Figure 1.11).

Within the abdominal cavity, the larva of the *Glossina* is fed on a secretion released from a specialised milk gland. The milk gland is located close to the head of the larva so that it can directly suck the milk into its gut. The larva breathes via abdominal polypneustic lobes and hence, gets its oxygen supply directly from air passing in via the female's vulva. The larva of the *Glossina* undergoes two moults at the same time as within the female's uterus and grows to a full size of around 6-7 mm, completely filling the abdominal cavity of female.

However, the female will terminate the pregnancy at any stage during the larval development if the conditions are not ideal for survival. This results in the ejection of under-developed larvae that are unable to successfully transform into viable pupae. In the wild, the female Tsetse fly looks for a suitable place to give birth to the larva. The sheltered area often comprises of an area of sheltered, loose, sandy soil. The birthing process is started by massaging the abdomen with the hind legs. The larva is born tail first, with the hard, black polypneustic lobes emerging from the vulva first, preceded by a droplet of clear liquid.

Once the polypneustic lobes are clear of the vulva the rest of the birth proceeds very quickly and is generally completed within a time period of 5-10 seconds.

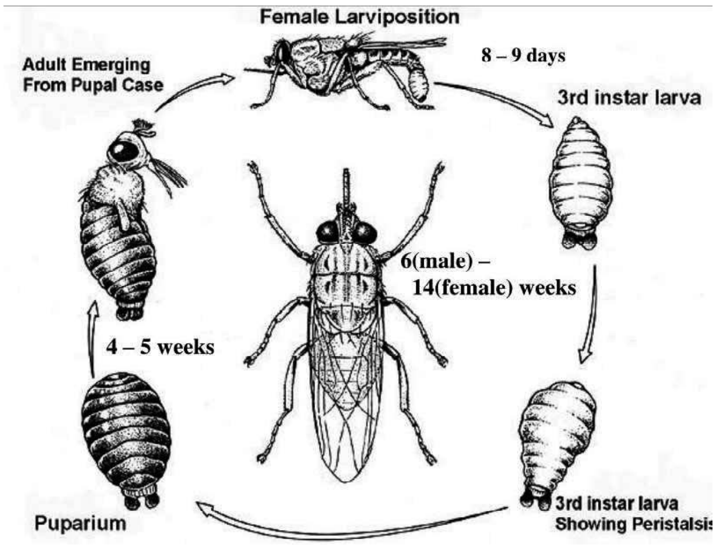

Fig. 1.11 *Life Cycle of Glossina*

5. Tabanid Flies (*Tabanidae*)

Tabanid adults are stout-bodied flies. They can usually be differentiated as horse flies or deer flies on the basis of numerous morphological characteristics. The antennae of the fly are prominent and extent anteriorly. Usually, they have a large size, outstanding appearance and mostly diurnal habits. The eyes of several species of Tabanid flies have shades of green, yellow, orange, as well as violet. They generally comprise of numerous ommatidial facets dorsally and smaller facets ventrally. The classification of tabanid flies is based on the division of antennae. Tabanids are pool feeders. They are fast flyers with high dispersal ability, for example, 1-2 km daily. One of the peculiar features of tabanids is the presence of variety and diversity of bold colours as well as patterns on different body parts like eyes, wings and abdomen. This variety and diversity of colored features helps in the identification of different species.

Tabanids are holometabolous insects. The entire life cycle of tabanid flies pass through four stages, i.e., egg, larva, pupa and adult. Eggs are generally laid in large, layered clusters of 100-1000 on vegetation as well as on other objects overlying water or moist soil (Strother, 1999). The entire process of embryogenesis needs two to 21 days. This time period varies from one species to species as well as it fluctuates on the basis of climatic conditions. For example, egg hatch rapidly when relative humidity as well as temperatures are high (Chvála *et al*., 1972; Mullens, 2002). Egg hatches and the larva which emerges out drop to the water or soil below where they become predators of other invertebrates or small vertebrates (Strother, 1999).

The colour of the larvae of Tabanids varies from white to tan. Tabanid flies are slender with a cylindrical body. Tabanid flies are found in a broad variety of biotopes having moist conditions. Larvae of Tabanid flies are majorly present in specific habitats, however their adaptability as well as hardiness also enable them to develop in other habitats.

On the basis of their habitats, tabanid flies can be divided in to three morpho-ecological groups namely:

- Rivulets (rivers) and streams.
- Slow moving or stagnant water bodies, or littoral areas (banks).
- Drier soil, usually far from water bodies as classified by Andreeva, 1982; Andreeva *et al*., 2009.

Hence, it can be seen that Tabanid flies occupy a wide range of habitats, i.e., aquatic, semi-aquatic or terrestrial. After hatching, they become predators of other invertebrates as well as small vertebrates. Usually, they feed on worms as well as larval forms of other Diptera. Sometimes, they also exhibit cannibalistic nature. Tabanid flies can generally tolerate hunger and hence, can survive without food for a very long period of time. Most of the species found in temperate regions have one generation per year, however, a few tropical species have two or three generations per year. Large temperate species may spend two to three years as larvae (Baldacchino *et al*., 2014). Once the larva of the fly is fully developed it moves into drier soil to pupate (Strother 1999). The number of larval stages ranges from 6 to 13. Pupation happens in dry places and generally lasts one to 3 weeks (Baldacchino *et al*., 2014). Finally, the adult flies emerge from the soil (Refer Figure 1.12).

Male Tabanid adults emerge before the female Tabanid adults. Shortly, after the emergence of adult flies mating happens. The mating between the male and female Tabanid flies happens in flight, especially in the morning time as observed by Wilkerson *et al*., 1985. After mating between adult Tabanid flies, adult females lay in wait in vegetation until a host for a blood meal wanders into range. Majority of the females look for a blood meal after mating except for non-hematophagous females like *Pangonius* sp., as well as autogenous hematophagous females as seen in *Tabanus nigrovittatus (*Greenhead horse fly*)*, which do not need a blood meal for the first oviposition. Females, specifically, the Tabaninae, attack majorly livestock, particularly large mammals like cattle, horses, deer, etc. *Chrysops* (Deer flies) and *Haematopota* (genus of flies in the horse-fly family) have a broad range of hosts including people. Oviposition generally occurs three to 11 days after feeding.

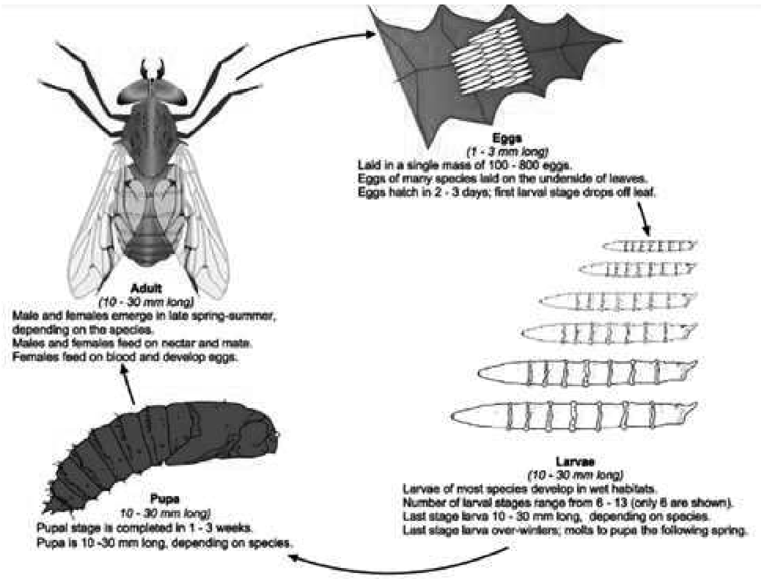

Fig. 1.12 *Life Cycle of Tabanid Fly*

Male and female adult Tabanid flies get their energy for several physiological purpose like mating, flight as well as body maintenance by obtaining sugars from natural plant.

The longevity of adult Tabanid flies is approximately two or three weeks; this is very short as compared to the larval stage as studies by Chvála *et al*., 1972. On the basis of species as well as geographical location, life cycles of the Tabanid flies need two months to two years to complete. Adults of most Tabanid species are only present for about one month, however, a succession of species is usually seen. The result is that livestock may be attacked by one or more species of Tabanidae throughout all or most of the warm months of the year as observed by Foil and Hogsette, 1994.

6. Black Fly (*Simuliidae*)

Adult male and female black flies mate shortly after they emerges from their larval form. The adult female black fly must look for a source of obtaining blood-meal to complete the development of her eggs. Egg development is completed within a period of 2-4 days. The adult female then looks for a river or stream in which to lay them. The choice of habitat for egg laying varies from species to species. It can range from a tiniest spring to the Mississippi River. The adult female black flies usually trap their victims from tree-top perches located near the edge of an open area. Black flies generally remain active during the day period with peak activity in the morning and early evening. Adult females live from one to three weeks. The life span depends upon the species as well as climatic conditions. They survive best in cool, wet weather.

After hatching, the tiny larvae start their life in the stream. Larva shows filter feeding, i.e., they filter the food coming from the running water with specially adapted mouth parts that resemble grass rakes. A fully grown larva is approximately 1/4 inch. On the basis of species as well as climatic conditions, a fully grown larva takes approximately 10 days to several months to develop completely. Larva then enters into the pupal stage where transformation to the adult stage takes place. The adult emerges out from its pupal case by riding a bubble of air to the surface (Refer Figure 1.13).

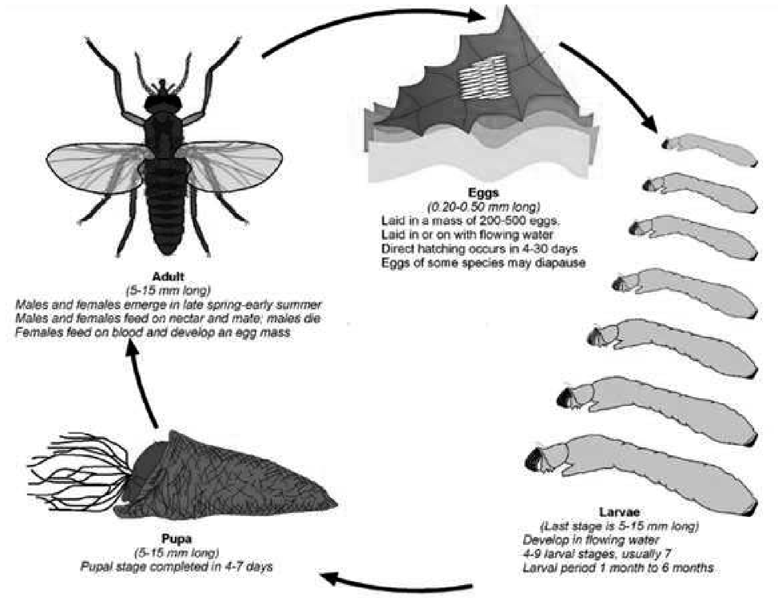

Fig. 1.13 *Life Cycle of Black Fly*

1.3.2 Non-Pathogenic Insects

Non-pathogenic insects are those insects that does not act as an intermediate or alternative host for a pathogenic organism. However, they can transmit life threatening disease to susceptible host by simply carrying the pathogenic microorganism on its external body. In parasitology, such organisms are known as **carrier**. A carrier referred to an organism which can spread the parasite by transmitting simply through different external body parts and which does not harbour any part of life cycle of parasite. Sometimes carriers are termed as mechanical vectors as they spread the parasite mechanically. Mechanical vectors are those organisms where the disease-causing agent or parasites (germs) are attached to the outside of their body, like in legs and thus transmit the germs or parasites from one host to another without involving any developmental stages of the parasites in their body. For example, housefly, cockroach, etc.

Here, the disease-causing agent or parasite is simply transferred by the carrier-agent. In this kind of mechanical transmission, the carrier does not harbour any part of life cycle of parasite, i.e., in other words the parasite does not stay or live within the tissue or cells of carrier. Hence, the spread of disease agent or parasite occurs only mechanically by different body parts through contamination. The transmission of diarrhoea, typhoid, dysentery, etc. by the housefly are examples of mechanical transmission of diseases. For example, insects like housefly, cockroach, etc., can spread the parasite simply by different external body parts through contamination.

1. *Musca domestica*

Musca domestica, commonly known as the housefly has been seen commonly by people everywhere except for those living in the poles. The life cycle of housefly is nearly similar to that of other insects. Female lay eggs which then develop into larvae. The larvae undergo three stages of Ecdysis to become a pupa. These pupas live stay inside a protective envelope known as **cocoon** and undergo metamorphosis to transform into the adult housefly. The entire cycle between being a fertilized egg to an adult house fly lasts only for 7 to 10 days; however, flies have a small life-span of fewer than 3 weeks. They do have the unbelievable ability to reproduce which safeguards their survival. *Musca domestica* is a holometabolous insect and the entire life cycle is divided into four stages namely egg, larvae, pupa and adult.

Once fertilized female lays approximately 75 to 100 eggs in a batch and around 500 eggs in 3 to 4 days. Houseflies are solitary creatures and hence they do not require nurturing from their mother to survive. The female housefly lays eggs in cracks or crevices where predators cannot reach and where there will be enough to eat upon hatching.

Housefly eggs need moisture to withstand/tolerate the environment, and hence the female flies are seen to lay eggs in moist places. The optimum temperature required for hatching of eggs varies from 25°C to 30°C.

Musca domestica lay eggs majorly in masses on organic materials like garbage or manure. Usually, many female flies will deposit their eggs close to one another, forming large masses of larvae as well as pupae concentrated at one area.

While laying eggs, the female fly also deposit a pheromone or semiochemical which further attracts other females to lay their eggs nearby. This leads to clustering of eggs.

The colour of housefly eggs is white and measures around 1.2 mm in length. These eggs hatch within a few hours and the larva emerges from it. The eggs usually hatch within a time period of 8 to 20 hours. The larvae begin feeding as soon as it comes out of the eggs. It begins feeding on the material on which the eggs are laid. The larvae increase their size rapidly and are found almost to double up their size in less than two days.

The larvae are creamy whitish in colour, cylindrical in shape and the size of the larvae which emerge out of the egg is approximately 3 to 9 mm. They feed via a hooked mouth. A peculiar feature of the larvae is somewhat raised position of the posterior spiracles as well as presence of an oval black border surrounding the spiracular openings. Spiracles are the external openings of trachea, i.e., respiratory tubes.

The nutrient-rich organic manure on which the eggs are laid and larvae emerges out and feeds helps them to grow quickly. Legless larvae emerging out from the egg can almost double its size in less than two days. Once it has become big, it undergoes the first molt. Molting refers to the phenomenon via which a growing insect sheds its former exoskeleton and grows a new one. The larvae undergo two more such molts emerging larger after each molt.

The skin of the larvae gets hardens after the third molt. The larva which has now grown enough, can crawl up to 50 feet to a dry, cool place located near the breeding material and dig into the soil or their breeding material. Larvae transform into pupas in these small holes and undergo metamorphosis. The best breeding grounds for a developing larva are provided by fresh swine and chicken manure. They have optimum nutrition which is required for the growth and development of the larvae, thus reducing the larval period, and producing larger pupas. On the contrary, manure does not serve as a suitable breeding place and thus creates smaller cocoons.

The optimal temperature required for larval growth varies from 15 to 38 °C though larval survival is highest at a temperature of 17 to 32°C.

At optimum temperatures, larvae of the *Musca domestica* requires around 4 to 13 days for complete development, and at a temperature of 12 to 17°C they take approximately 14 to 30 days for full development (Refer Figure 1.14).

The pupa of the *Musca domestica* measures around 8mm in length. The colour of the pupal shell varies from yellow, red, brown and finally to black as the pupa ages. The shape of the pupa is entirely different from that of the larva as it is bluntly rounded at both ends.

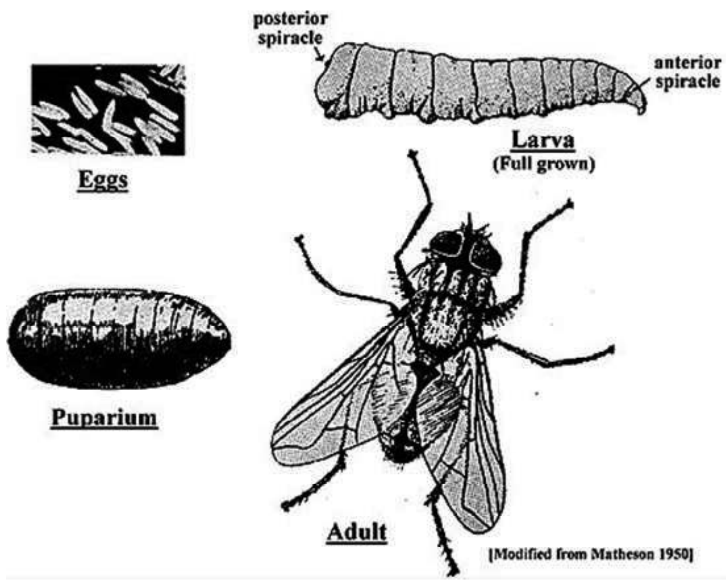

Fig. 1.14 *Different Life Stages of Musca domestica*

Pupa undergo metamorphosis within the pupal shell. Time required by pupa to undergo metamorphosis depends upon the temperature. The optimum temperature for the development of the pupa ranges between 32 to 37°C. If the temperature is between 32 to 37°C, the metamorphosis happens in two to six days, however, if the temperature is around 14°C, it can take anywhere between 17 to 27 days for metamorphosis. The effect of temperature can be seen from the example that in temperate regions, 12 generations of houseflies may occur in one year, however, in tropics and subtropics, more than 20 generations arise in one year.

The only morphological difference between a fresh housefly emerging out of the shell and an adult housefly commonly seen is a bulge present on their head region. Houseflies lack teeth as well as jaws to chew its way out of the cocoon. Thus, the bulge which is commonly referred to as the ptilinum acts as a pneumatic hammer to break open the cocoon shell. The ptilinum is a fluid-filled sac that swells and shrinks alternatively acting as a pneumatic hammer. Once the fly is out of the pupae shell, the bump deflates back into the fly's head. The adult male and female house flies attain sexual maturity around 16 to 24 hours after emerging from the pupa, respectively. The adult house flies in the wild lives only up to 2 weeks, so reproduction is essential to ensure the sustenance of the species.

The lifespan of adult housefly that emerges from out from the pupa is approximately two weeks to a month in the wild, or longer in laboratory conditions (Refer Figure 1.15).

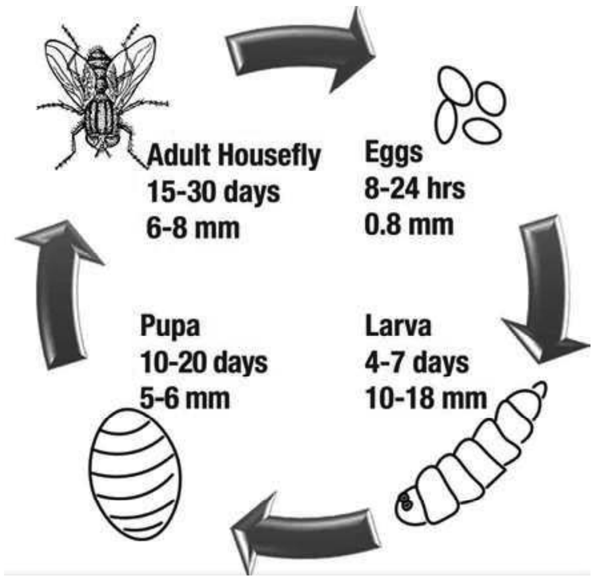

Fig. 1.15 *Life Cycle of Musca domestica*

Adult male and female flies differ from each other in following morphological characters:

- Female adult houseflies have larger wings as compared to adult males.
- Adult males have longer legs as compared to adult female. The longer legs of the adult male make it easier for them to climb on to the female during mating.
- Adult female houseflies tend to vary in size.
- Adult female flies in the higher latitudes are larger as compared to the ones observed in lower latitudes.
- The pair of compound eyes on a male almost touch each other while in females they are widely separated.

Sexually mature adult female houseflies produce a pheromone (Z)-9-tricosene to attract potential mates. (Z)-9-tricosene is not released into the air; as an alternative, the male house flies smell it only when they come in contact with other females. (Z)-9-tricosene, the pheromone produced by the female flies are a suitable pest controller. It is widely used to lure in and kill the male flies, and it is environment friendly too.

Houseflies are seen to mate in the air and on the ground. The process of mating is initiated by bumping into the adult female, which is known as a **strike**. When the adult male flies come in contact with the adult female, it smells the pheromone, i.e., (Z)-9-tricosene.

After striking, if the male smells pheromone, (Z)-9-tricosene, it climbs over to the thoracic region of the female to check whether it is receptive or not. If the female is not receptive, then the male flies away.

However, if the female is receptive, then it followed by a period of courtship. The female fly starts to vibrate its wings (as a suggestion of being receptive), and the adult male mildly strokes its head. The male housefly then moves its abdominal region where the female ovipositor is situated. The female pushes her ovipositor into the genital opening of the male and spermatic fluid is deposited in the female. The adult female mates only once in its lifespan, however, male mates numerous times.

The adult females generally store the spermatic fluid in them and use it to fertilize her eggs later. This phenomenon explains how a female can lay eggs five to six times in one lifetime even though it mates only once in its lifetime.

2. *Periplaneta americana*

Periplaneta americana (American cockroach) is one of the large-sized insects. They are also commonly known as waterbugs in certain parts of the world. These are some of the oldest insects whose fossils are 320 million years old. The distribution of cockroaches is quite diverse in nature and it is majorly found in tropical and damp climates. They are mostly considered to be pests and generally inhabit places like kitchens, bakeries, godowns, storerooms as well as sewage channels. Cockroaches are known for leaving behind stinky smells, attacking household food items, and are considered to be carriers of diseases and henceforth are hated everywhere they are found (Refer Figure 1.16).

The adult is reddish-brown in colour. It has an average length of around 4 cm. These animals have yellowish margins on the pronotum. The body of the cockroach is dorso-ventrally flattened, distinctly segmented and covered by a shining brown exoskeleton.

The body of the cockroach is divided into three separate parts namely head, thorax, and abdomen. Wings that are darker than the body itself generally covers the dorsal body surface. Cockroaches are nocturnal and omnivorous animals.

The development as well as the lifespan of a typical cockroach depend upon several factors like environmental conditions, diet, humidity, rainfall, nutrition, etc. A frequent cockroach can survive from 2 months to 2 years depending upon its breed (Refer Figure 1.17 and 1.19).

Favourable environmental conditions can lead to the rapid development of the body of the cockroach and allow them to breed more frequently in their life

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while unfavourable conditions usually shrink the cockroach size and may also lead to their early death.

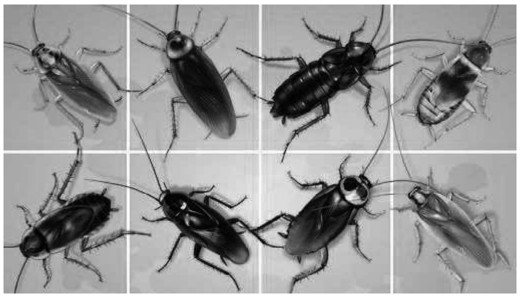

Fig. 1.16 *Different Breeds of Cockroach*

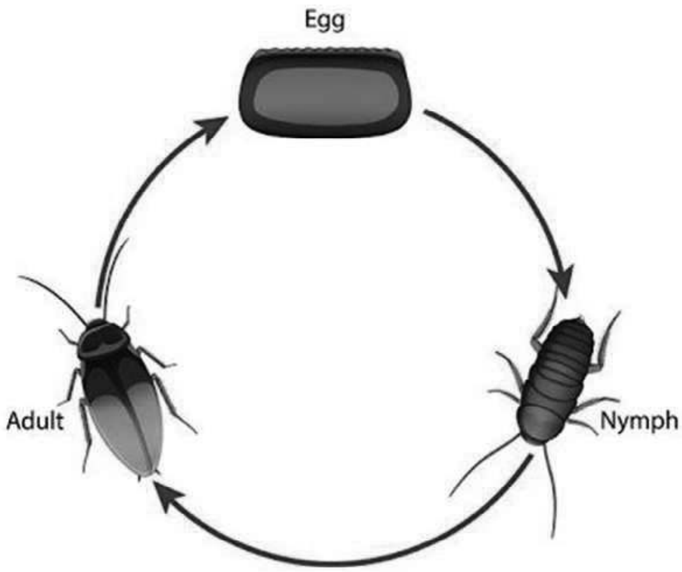

Fig. 1.17 *Life Cycle of Periplaneta americana*

Apart, from the environmental factors, other factors like the availability of food as well as shelter also affect the life span of this insect. In their lifetime, cockroaches will reproduce, lay more eggs as well as give birth to numerous other cockroaches. The three main factors which have a huge impact on the lifespan of a cockroach are:

- **Breed:** Different species have different lifespans.
- **Environment:** Several factors like temperature, humidity plays a crucial role in their development.
- **Diet:** Availability, quality as well as the quantity of the food has a major impact on the overall development of these insects.

The life cycle of a cockroach is divided in three stages that are explained below (Refer Figure 1.18):

Stage 1: Egg

The adult female cockroach lays approximately 10 to 50 eggs in one term in warm and humid conditions. The eggs are covered in the eggshell covering known as ootheca sac. This ootheca sac is located at the abdomen of female cockroaches in order to protect them, till it enters the nymph stage.

It takes cockroaches approximately one to two months to hatch, however, the egg stage lasts around 14 to 100 days depending upon the climatic changes in the environment. An increase in the rate of development has been observed at higher temperatures. On an average, a female cockroach lays approximately 300 – 400 eggs in a year.

Stage 2: Nymph

The second stage of a cockroach lifecycle is known as the nymph stage. This nymph undergoes several stages of moulting, shedding skin and growing a little with each molt. Gradually, the nymph becomes larger in size. In its earlier stage, the nymphs are white coloured soft bodied insects. Later on, this exoskeleton hardens to become more rigid and darker in colour.

The time period for this stage varies from one species to another and also hugely depends upon the environmental factors and presence of predators. This nymphal stage generally lasts for 11 to 14 months, depending on various circumstances. Nymph becomes fully functional in their last molt. After the completion of the nymph stage, it develops wings partially and enters into the adult stage of their life.

Stage 3: Adult

In the adult stage, the wings become fully developed and it becomes one of the peculiar features to differentiate between an adult and a nymph stage. The lifespan of the adult enormously differs from one species to other species and depends upon several environmental factors. Depending upon the species and other environmental factors, the lifespan varies from 2 months to 2 years.

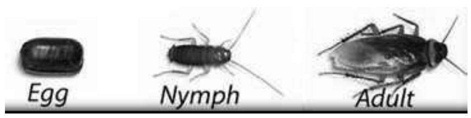

Fig. 1.18 *Egg, Nymph and Adult Stages of Cockroach*

Cockroaches are omnivorous animals as they feed on almost anything. For survival purposes, they usually prefer a warm, dark-dingy, and humid climate to survive.

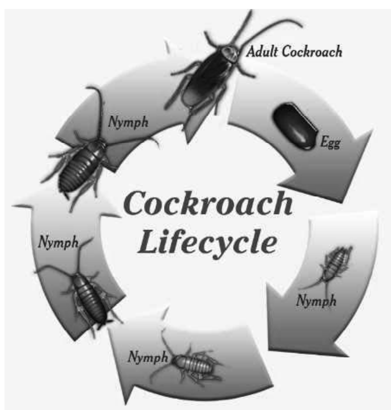

Fig. 1.19 *Life Cycle of Periplaneta americana*

3. Ants

Ants are holometabolous insects like other social insects, i.e., bees, wasps and hornets, ants undergo a metamorphosis in four life stages: egg, larvae, pupae and adult. The entire process can take up to 60 days from start to finish. The eggs of ants are tiny, white in colour. Fertilized eggs produce females, on the contrary unfertilized eggs becomes males. After some days depending upon the species, the eggs hatches and larvae comes out from it. The larvae looks for constant nourishment and hence begins feeding. A single larva grows so rapidly that it molts (sheds its skin) several times during this phase, which lasts between seven and 14 days. Pupal stage is the third stage in which few species spin protective cocoons, while others remain uncovered. Once the adult surfaces from a pupa, it is fully formed and ready to go (Refer Figure 1.20). The members of an ant family are described below:

Queen

A queen is larger in size when compared to other members present in the colony. A queen will lay eggs that hatch into new queens with wings that they use to fly out of the nest to mate (queens are the only females able to reproduce). Once a new queen locates a spot to nest, she lays her eggs, then feeds and grooms the hatched larvae until they turn into cocoons (or remain uncovered depending on the species). In a few weeks, new adult workers emerge and the colony is officially up and running.

Drones

Drones are fertile, winged males. The only purpose served by drones is to impregnate a queen. After this, drones are not required in the colony and male generally dies within a few weeks.

Workers

Workers are always present in majority of an insect's colony. They perform all the duties like foraging for food, burrowing tunnels, warehousing food and tending to the larvae while staying in the colony. Workers and soldiers (larger workers who defend nests) can survive as long as seven years. The average lifespan of an ant varies from a few weeks to 15 years depending upon the species, the function played by the ant as well as the availability of food sources. For example, a black garden ant can live almost two decades, while fire ant workers are expected to live less than a month.

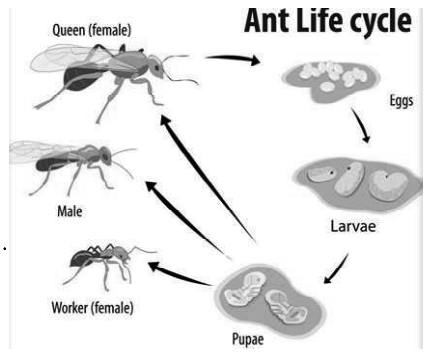

Fig. 1.20 *Life Cycle of Ants*

Water Borne Human Diseases Caused by the Insects

Infectious diseases spread from infected person to healthy ones via several routes like air, food, water, etc. Water borne diseases are referred to as those diseases that spreads via drinking or using contaminated water. Water generally gets contaminated under poor hygienic or in-sanitary conditions. Contamination can occur either at the source of water supply, while passing through water pipes, which are broken, or at homes too when water is not stored properly. The water can be contaminated with either human or animal faeces and the diseases transmitted by drinking such water are known as faeco-orally transmitted diseases. Water borne diseases can also be transmitted through eating food prepared using contaminated water or using utensils which have been washed with the contaminated water.

Transmission of Water Borne Disease by Insects

Insects like house flies and cockroaches are mainly responsible for spread of water borne diseases. Water borne diseases are caused by viruses, bacteria, protozoa and even nematodes (worms like the roundworm or threadworm). There are more than 100 pathogens (disease-causing organisms) that are associated with both house flies as well as cockroaches. Unlike other insects, such as mosquitoes or ticks, these pathogens do not specifically require an insect vector. The house flies or cockroaches plays no specific role in the life cycle of these pathogens. They simply act as a carrier of disease. Diarrheal illnesses are one of the most common water borne disease spread by these insects. The causative agent is *E.coli*, *Shigella*, *Campylobacter*, *Enterococcus* and related bacteria which generally cause diarrheal illnesses and are found in the stool of people with these illnesses. Some of the common water borne diseases spread by the insects include: Cholera, Dysentery, Food poisoning/gastroenteritis, Typhoid fever, etc. Thus, it can be concluded that these insects can spread several infectious diseases extensively.

House flies as well as cockroaches are able to spread disease via many routes. They do not bite like the horse fly or tsetse fly in order to inject the pathogen into a person. Instead, the disease-causing agents are spread on its body, in its mouth parts or through its saliva, vomiting or faecal matter. House flies feed indiscriminately on a wide range of organic matter, from feces to food (fruits, vegetables and meat). It is through this contact with the item it is feeding upon and even direct contact with people that disease-causing agents are acquired and passed on.

The infective dose for each pathogen like bacteria, virus, etc., varies significantly. Occasionally, a few microbes are necessary to cause serious disease. The contaminated matter containing these microbes, and even just the microbes itself, that are acquired from one source may adhere to the fly or be passed out in its vomitus, saliva, faecal matter, etc. The contaminated matter and microbes are then passed onto food once the fly lands and/or feeds on it. The situation is gets further worsened if the food is not refrigerated allowing the inoculation dose of microbes to multiply rapidly before the food is eaten.

These insects generally need just a few seconds to make contact with a source of pathogens and pass on it somewhere else. Faeces is one of the substances that are laden with a wide range of microbes, particularly if it was passed from a person who was ill.

House flies or cockroaches cannot be completely eradicated. Application of insecticides or pest control can reduce their population for a limited period of time; however, they can come back quickly. In order to prevent diseases, their contact with people, food and eating utensils should therefore be prevented or interrupted

Treatment of Houseflies and Cockroaches Responsible for Spreading Water Borne Diseases

House flies and cockroaches are common insect that it is considered part of everyday life for humans. Even though, most of us see these insects as a source of irritation, buzzing around and trying to feed on any food it can access within the home, however these insects can also transmit diseases. In fact, many common infections are transmitted by both houseflies as well cockroaches as mentioned above. A few diseases transmitted by them are very serious and even potentially deadly. Although, they can never be eradicated entirely, reducing their populations and limiting its contact with food in particular is an important part of hygiene.

A few methods that can be used to control houseflies and cockroaches are as follows:

- Removal of breeding places: Maintenance of cleanliness is an effective method to bring down population of house fly.
- Treatment of breeding places: Cover the breeding grounds with a layer of insecticide dust, such as 5% DDT to prevent flies to feed and lay eggs.
- Adults can be killed by spraying insecticide, such as malathion, Baygon, lindane, carbaryl or endosulfan.
- UV emitting electrocuting trap are quite effective in attracting and killing adults.
- Biological control: *Spalangia,* has been found to be very effective in destroying pupae of houseflies.
- Thoroughly, clean the house at least weekly.
- Pay special attention to the kitchen as well as other areas where food is prepared regularly.
- Clean regularly underneath the fridge, stove, toaster as well as other movable appliances.
- Empty the kitchen's rubbish bin regularly.
- Do not leave out pet food or food scraps in pet bowls.
- Clean up any food spills promptly.
- Make sure there are no sources of water, such as a dripping tap, as cockroaches need a steady water supply to survive.

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- Store food in sealed containers.
- Repair any holes, cracks or gaps in the walls, skirting boards and inside cupboards.
- Do not stack newspapers, magazines or cardboard boxes anywhere in the house.
- Keep compost bins screened and away from the house.
- Use appropriate insecticide and follow the manufacturer's instructions.
- Cockroach baits contain poison that a cockroach carries back to the nest, which may help kill the rest of the nest.
- Use physical traps, such as greased margarine tubs containing a smear of honey as the lure – cockroaches will climb in for the food, but be unable to get out because of the grease (or oil) on the tub.

Check Your Progress

4. What are pathogenic insects?
5. Define vector.
6. What is biological transmission?

1.4 COLLECTION AND PRESERVATION OF INSECTS

Following are the methods and equipments for collection of insects:

Collection of Insects

Entomologists collects insects for variety of reasons. The collection of insects helps to identify and research the specialty of pests. It helps to educate people regarding different types of disease-causing insects as few insects spread diseases like malaria, etc. Insects are also collected for entertainment purpose and it reduces the stress as some insect specimens are naturally beautiful to the eye. Further, unlike the big animals, collecting insects does not require any licence or permission from the authorities. It is also done in numerous schools, universities and educational institutes round the globe as it helps students to gather knowledge about their environment, habit, etc. Insects can be easily found in agricultural fields, rotten wood, the under surface of leaves, dry leaves, under loose bark as well as stones, kitchen pantries, street light or night light, etc. There are numerous methods to collect insects as well as arthropods. However, the method of collection as well as tools and techniques employed in insect collection varies with the insect and hence a specific protocol needs to be followed. In this section, a few general insect collection methods are described.

Collection Content of Insect and Arthropod

Collection event comprises of the following:

a. Collection as well as preservation of insect.

b. Information regarding the insect sample like name of the collector, date of collection, locality from where insect is collected, and habitat/food source of collection.

Collection of Insects

Collection of insects and arthropods depends upon the insect as well as the purpose of collecting insects. For example:

- **General Collection**: This type of insect collection does not target any specific group of insect/arthropod. The purpose of this type of collection is to survey a particular locality/habitat for the kind of insects present in it.
- **Targeted Collection**: This type of insect collection targets a specific group of insect/arthropod.
- **Casual Collection**: This type of insect collection has no specific purpose. An insect is encountered by chance and is collected by the researcher/ entomologist to determine its identity.
- **Formal Collection**: The targeted insect is collected with a standard/specific protocol.
- **Qualitative Collection**: As the name suggest, this type of insect collection does not attempt to quantify collecting effort/sample size/catch, etc. The major interest of this insect collection is to determine the presence/absence of a particular species or group of interest.
- **Quantitative Collection**: In this type of insect collection, different aspects of the collections are held constant like area, time, effort, etc. Collection events (samples) can be compared among one another.

Insect Collecting Equipment and Devices

There are several devices and equipment's which are used for collecting insects. Below are the equipment's and devices used for collecting insects:

I. Equipment Used to Collect Insects

i. Insect Nets (Aerial Netting and Sweep Netting)

Insect Nets (Both Aerial and Sweep Nets): Three basic kinds of insect collecting nets are available commercially for purchase in market. These are aerial insect collecting nets, aquatic insect collecting nets, and sweeping insect collecting nets (Refer Figure 1.21). Mostly, a collecting insect net comprises of some kind of net bag made up of cloth or fine mesh that is attached to a wire hoop, which is affixed to a wooden or metal pole. Nets are available in different sizes with few having the circumference being smaller as compared to others and with adjustable pole lengths as well. Aerial nets usually comprise of net bags that are composed totally of meshed material and generally have a lightweight handle. Aerial net bags are generally white in colour, however, black net bags are also available. Insect nets are mostly useful for catching selective insects that might be flying or perching on some object like dragonflies, butterflies, bees, or wasps, etc. Aerial nets having larger hoops are good for collecting large as well as quickly moving insects like dragonflies and butterflies, although those having small hoops are good for other insects like bees, flies, wasps, as well as other smaller insects. In the tropical areas, very long handled nets are used for gathering butterflies that are present high in trees.

Sweep nets are generally composed of a heavy material (like canvas) that can be dragged via dense vegetation without being damaged. Sweep nets generally have heavier handles as compared to others. Sweep nets are used to sweep through vegetation to gather accidental insects which are not easily seen.

Generally, in insect labs, a combination of aerial as well as sweep nets are also generally used, with the majority of the net bags composed of a heavier cloth and around the apical third of the bag is made up of fine mesh material. Aquatic nets are heavy duty net bags and comprises of handles as well as have square to triangular thick wire hoops. Aquatic insects are collected by dragging the net through the substrate of aquatic habitats and then depositing the accumulated material into a large white pan to sort through.

Fig. 1.21 *Different Types of Nets*

In above Figure 1.21. different types of nets are show in in which large brown net depicts the sweep net, circular white net is a combined type of net, the dingy white net is an aquatic net, fourth one, i.e., the black mesh net is an aerial net.

ii. Collecting Jars and Bags

- **Jars and Bags:** Containers like jars or vials (smaller jars) are one of the most useful collecting tools for many insect species. Jars and bags can be used to collect specimens by placing the jar lip over the insect to capture it and then using a card to slide under the inverted jar to seal the insect inside before placing the lid on it. Non-flying kind of insects can be beaten up from plant foliage into the jar to capture them, on the contrary, insects that can be hand are placed directly in the container. One of the method for sampling insects in cotton fields, is known as **beat bucket**, utilizes a 5-gallon plastic bucket. Terminal ends of cotton plants are 'beaten' in the bucket to remove insects where they can be easily counted or collected. Home gardeners simply utilizes an empty coffee can to beat pest insects like Colorado potato beetle (*Leptinotarsa decemlineata*) larvae from plants as a control measure.

- **Zip-Lock Sandwich Bags:** Zip-lock sandwich bags serve as the excellent containers during field collections. One of the biggest advantages of using zip lock bags is they are light weight, required less space and hence can be carried easily while travelling to field for collecting insects. Insect specimens can be separated by groups in such a way that large active insects do not damage smaller delicate specimens, and once inside the bag, air can be removed to limit movement of the specimens to prevent any injury. The bags containing specimens can be frozen before further processing (Refer Figure 1.22).

Fig. 1.22 *Containers Used for Collecting Insects*

- **Cockroach Trap:** As the name suggests, it is used for collecting cockroaches. Any clean clear glass jar is appropriate for this purpose. A layer of mineral oil along with vaseline is used to coat the inner layer of the jar. Tempting food particles like peanut butter and/or bananas in placed in the jar and then place it in an area where cockroach are engaged actively. Keep the jar as such overnight. Cockroaches entering into the jar will fail to escape. The jar containing the cockroach can then be placed in a freezer in order to kill the specimens for mounting or preservation in alcohol. Sometimes, they can be used to begin a fresh culture for laboratory purpose. The biggest advantage of this cockroach trap over the commercially available box-type sticky traps is that specimens collected are clean and living.
- **Food Baited Jars**: A lot of decaying objects can be used for to collect insects. For example, an over ripe banana can be placed in a glass bottle or any other appropriate container and this can be used for collecting insects. Similarly, placing decomposing canned meat products like tuna fish will attract house flies as well as bottle flies to lay eggs on the substrate (carrion). In this way immature stages (maggots) of these insects can be obtained. A bucket full of clear rainwater is a breeding ground for mosquitoes.
- **Cricket Cages:** Cylindrical wire-mesh containers with a plastic sleeve in the middle of the top are usually used for collecting crickets.
- **Sorting Trays:** Metal or plastic trays are generally used in laboratories to sort the insect from other material like soil, debris plant materials, etc.

iii. Aspirator

An aspirator is a device which is frequently used for capturing small insects like aphids, whitefly, etc. The general design of an aspirator comprises of a vial (usually plastic or glass) and a tight fitting cork, rubber stopper, or other cap having two rubber tubes running through it. One of the tubes has a rubber hose several inches long connected to it and a piece of fine mesh attached to the other end of the tube inside of the vial. In order to gather insects, one end is used to suck air through the rubber hose and points the other tube at the insect and the insect is sucked into the vial. As the end of the tube which is used to draw air through has mesh over its end, insects in the vial are not sucked into ones mouth.

iv. Collection Kit

Collection kits are available commercially in the market. They are used for collecting insects and contains all the essentials for identifying as well as collecting insects for a beginner or budding entomologists. The items present inside the container kit available commercially are as follows:

- A net (which can be used to catch all kinds of critters).
- A glass-top insect box with a foam pinning block or board.
- An identification field guide as well as other equipment for creating and adding to the insect collection.
- A magnifying glass to have the perfect close view of the insect.

v. Beating Sheet

The beating sheet is also known as the beating net or beating tray. It is a device that is used for insect collecting. Typically, it is used under a tree or on a wooden or metal frame. It is a great way to survey particular plants for insects.

vi. Collecting Container

Collecting containers varies from small to large in size 240 - 960ml with a good visibility. These pint-sized containers are suitable for breeding small colonies of insects in laboratories as well as other limited spaces. They are frequently used for shuttling the insects from one place to other. These collecting containers can serve as temporary enclosures to suitably confine insects captured in the field. The main advantages of using insect containers is that it is highly visible, has specific snap features that prevents the block the escape route of insects, can be used for understanding the biology or life cycle of an insect in laboratory, they are very handy and convenient to use and most of all they can be taken to the fields for collecting insects. The highly breathable screen pre-installed on the donut lid top snap cap is of 24 x 24 mesh netting made of nylon used particularly for insect rearing. Tainted screens can be easily replaced with fresh ones sold separately. The donut lid of the pint-sized insect pot has a matte surface for penciling notes. To assemble a pint-sized insect pot, simply snap down 3 built-in clips around the rim to secure the lid to the pot.

II. Devices Used to Collect Insects

i. Vacuum Device

Vacuum device is kind of suction device that has been developed to collect insects as well as other related arthropods. These vacuum devices are hand-held and battery-operated. They can be used to remove spiders, mosquitoes as well as other insects seen in the home, and a few of these can be adapted to become collection tools. Apart from small hand-held vacuum devices, there are large vacuum devices, known as backpack aspirators, which are commercially available and utilize gasoline or electric motors to create suction. These large devices can remove insects as well as other debris from crops or turf grass. A few huge tractor-mounted vacuum devices are available in the market for collecting insects.

ii. Tullgren Funnel

Tullgren funnel refers to an ordinary funnel into which a handful of soil or leaf litter (generally this leaf litter is supported by a layer of mesh) is placed (Refer Figure 1.23). The tullgren funnel is placed suitably above a jam jar or other collecting vessel having slippery sides and with a piece of somewhat moist tissue paper can be placed at the bottom of the jar. A light is then placed in such a way that it shines on the substrate within the funnel. After few hours, the insects, mites as well as other invertebrates present progressively work their way down, moving away from the source of light and heat, and fall into the jar from where they can be collected, observed and studied or examined.

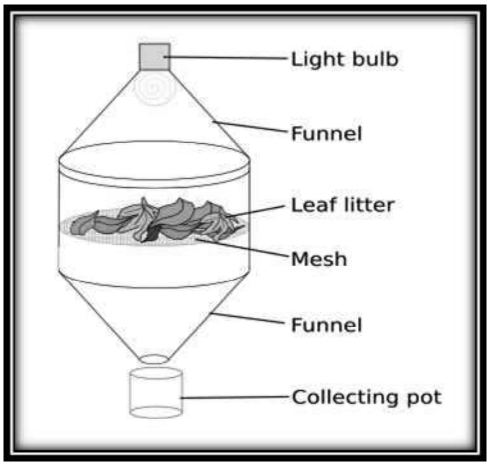

Fig. 1.23 *Tullgren Funnel*

iii. Light Trap

The light trap is a great way to collect insects at night. It has three parts: a light, a funnel and a container. Light-attracting insects will fly to the light bulb, drop into the funnel, and afterward fall into the bucket. Insects like Armyworm, bugs, cutworm, flies, gnats, bollworm, leafhoppers, planthoppers and stem borers can be collected by using light trap (Refer Figure 1.24).

Light traps can be made easily by using plastic buckets 5-10 lts, metal light shade, fluorescent light with holder, electrical wires, coated metal rods, tin sheets, string/ flexible wire, nut bolts and screws, rubber plug for drainage hole and soap water or kerosinized water.

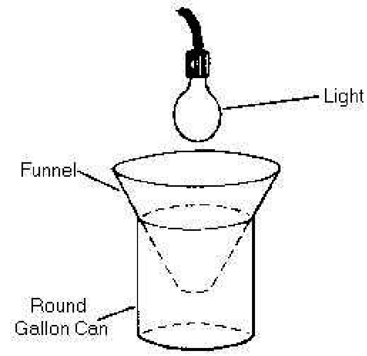

Fig. 1.24 *Simple Light Trap*

iv. Pitfall Traps

A pitfall trap is a device which is used to capture pests that are active on the ground. In order to make a pitfall trap, bury a plastic bowl up to the edge and level the backboard with the ground surface. Fill the bowl with enough water to cover the bottom, then add one drop of liquid soap. Insects crawling along the ground's surface will fall into the bowl and be unable to escape. A pitfall trap comprises of some type of cup or other container that is submerged in the soil and then somewhat filled with a preservative. Insects as well as other invertebrates crawling about on the ground merely walk into the container and after this cannot get out. Pitfalls can be covered to prevent them from filling with excess of rainwater. Further, they can have some kind of guide strips that might lure/attract the insects or other invertebrate organisms into the cup, and they may be baited to capture more particular types of insects.

v. Malaise Trap

A malaise trap is a large, tent-like structure used for trapping, killing, and preserving flying insects, particularly Hymenoptera and Diptera. The trap is made of a material such as PET (polyester) netting and can be various colours. Insects fly into the tent wall and are funneled into a collecting vessel attached to its highest point. It was invented by René Malaise in 1934. Malaise traps are basically tent-like traps which are made up of fine mesh material which is used majorly for the collection of flies (Diptera) as well as wasps (Hymenoptera), even though, they also catch several other flying insects. Malaise traps are usually set out for long periods of time as well as checked at least weekly, or occasionally every other week. Generally, a malaise trap has two short end walls, one central wall, and a roof, that is only peaked on one end, or in some styles, both ends. The walls of the malaise traps are usually black in colour, whereas the roof is white. Poles, wooden or some other material are frequently used to support the trap at each corner as well as at the peak in front. It is supportive if the front pole is adjustable in such a way that the sample jar can be raised or lowered conveniently. The poles are in turn tied to stakes placed in the ground several feet away. If it is necessary, the ropes (or strings) may be tied to something. Insects that hit the middle mesh wall will fly either in upward or downward direction. Those insects that fly upward are funnel to the peak of the trap and ultimately find their way into a jar with some killing agent like alcohol. Alcohol also helps in preserving the insects. Once the malaise trap has been set up fully, it must be placed at an ideal location for collecting the insects. Generally, they are placed at right angles to an insect flight line.

Preservation of Insects

Collected insects are then killed slowly with the application of potassium cyanide gas slowly released in a capped wide mouth jar. Entomologist employs a variety of ways to preserve insects:

i. Pinning

Pinning is one of the best ways to preserve hard-bodied insects. Entomologist generally used a special kind of steel pin known as insect pin for pinning insects. The size of the insect pin ranges from 00 to 7. The most commonly used pin size are of size 2 and 3. The advantages of pinning an insect are as follows:

- Pinned specimens keep well.
- It is easier to handle pinned specimens for carrying out further studies.
- Pinned specimen retain their normal appearance.

Insects are usually pinned vertically through the body. The easiest way to pin an insect is to hold it between the thumb and fore finger of one hand and insert the pin with the other. All insect specimens should be mounted at even height on the pin, leaving around 2.5 cm free above the insect surface.

The methodology used for pinning some of the insects is explained below:

- Insects like bees, wasps, flies, butterflies as well as moths are pinned via the thorax between the bases of the front wings.
- However, with insects like flies and wasps it is required to insert the steel pin a slightly to the right of the midline.
- Further, bugs are pinned through the scutellum, slightly to the right to the midline.
- Grasshoppers are pinned through the posterior part of the pronotum, slightly to the right of the midline.
- Beetles are pinned through the right elytron, about halfway between the two ends of the body; the pin should be carefully inserted through the metathorax and emerge out from the metasternum to prevent any damage to the base of the legs.

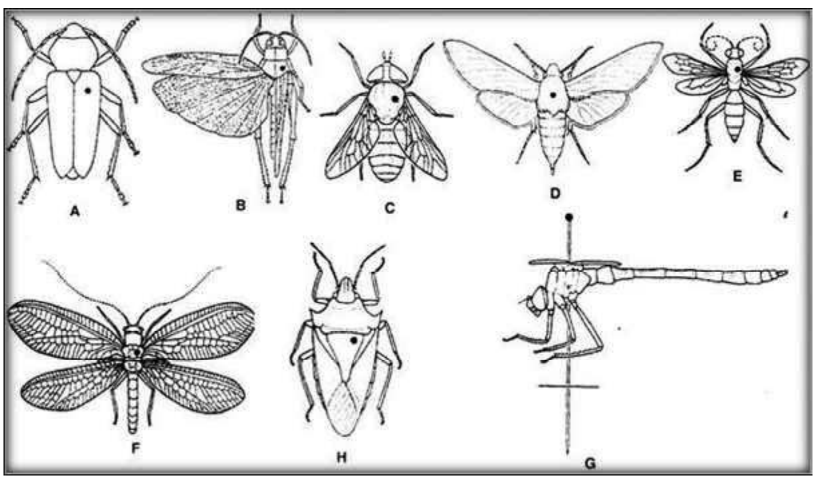

Fig. 1.25 *Pin Positions (Black Dot) For Different Insects*

In above Figure 1.25 pin positions (black dot) for different insects is shown in which A. shows beetles, B. shows grasshopper and crickets, C. shows flies, D. shows moths and butterflies, E. shows wasps and sawflies, F. shows lacewings, G. shows dragonflies and damsel flies; and H. show bugs.

ii. Mounting Small Insects by Card Point

Small insects should be mounted on a card point or on a minuten pin. The card points are elongated triangular shaped pieces of light cardboard or celluloid with dimension as 8 to 10 mm long and 3 or 4 mm wide at the base; the card point is pinned through the base and the insect is fastened/glued to the tip of the point. In order to preserve insect with the help of card point, point is put on the pin and the upper side of the tip of the point is touched to the glue and then touched to the insect.

iii. Spreading of the Insects

Collected insects are pinned and then spread on a spreading board with the dorsal side up. There are specific positions for the wings of a spread insect. For example, the rear margins of the front wings should be straight across, at the right angles to the body; and the hind wings should be far enough forward that there is no large gap at the side between the front and hind wings in the case of insects like moths, butterflies as well as mayflies (Refer Figure 1.26).

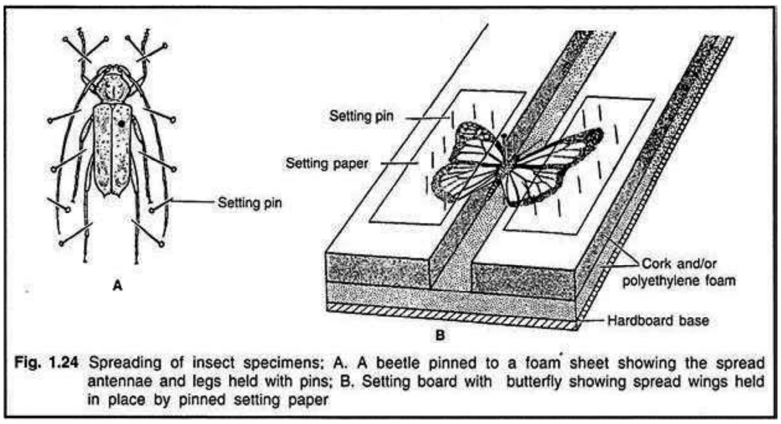

Fig. 1.24 Spreading of insect specimens: A. A beetle pinned to a foam sheet showing the spread antennae and legs held with pins; B. Setting board with butterfly showing spread wings held in place by pinned setting paper

Fig. 1.26 *Spreading of Insects Specimens*

In above Figure 1.26 spreading of insect's specimens is shown in which A. shows beetle pinned to a foam sheet showing the spread antennae and legs held with pins; and B. shows setting board with butterfly showing spread wings held in place by pinned setting paper.

Labelling of Insects

Labelling of insect involves the information:

- Date of its collection.
- Area from where it is collected.
- Habitat/food plant from where it is collected.
- Name of the collector.

Pinned insects should be saved in boxes having a soft base so as to permit the easy piercing of insects. All the preserved insects are susceptible to attacks by pest and hence necessary precautions should be taken. Generally, entomologist keep naphthalene balls/flakes in boxes containing pinned insects. Another substance, Paradichlorobenzene (chlorinated aromatic hydrocarbon) can also be used, however it volatilizes more rapidly and hence requires renewal more frequently.

Preservation of Insects in Fluids

Though pinning is an excellent technique to preserve insects, however, soft bodied insects cannot be pinned and must be preserved in fluids. For example, insects like Aphids, insect larval forms, insect nymphs, Mayflies, Stoneflies, Myriapods, Crustaceans, Arachnids and Caddisflies should be preserved in fluid. Further, insects like Fleas, Lice, Springtails as well as other minute flies are preserved in fluid before they can be mounted on microscopic slides. The most common solution used in this method is XA solution, i.e., xylene-alcohol solution. The chemical composition of the mixture is one part of xylene and one part of ethyl alcohol (95% ethyl alcohol is used for making mixture). Insect larvae killed using XA solution should be transferred to 75% alcohol after 24 hrs as XA solution removes the bright colours especially green, red and yellow from the larvae.

Identification of the Collected Insect

Insects are identified throughout the world by several national and semiofficial organizations:

- Zoological Survey of India, Calcutta.
- Division of Entomology, Indian Agricultural Research Institute, New Delhi.
- Indian Forest Research Institute, Dehradun.
- The British Museum, Queens Gate, London, U.K.

Check Your Progress

7. Why entomologists collects insects?
8. What are the event of insect's collection comprises of?
9. Name the devices and equipment's used for collecting insects?

1.5 INSECTS AS CARRIERS OF PLANT DISEASES

A vector is an organism capable of transmitting pathogens from one host to another. The insects, besides directly damaging the crops, sometimes become responsible for the spread of pathogens in plants.

Insect Vectors of Plant Diseases

All those insects which acquire the disease-causing organisms by feeding on the diseased plants, or by contact and transmit them to healthy plants are known as insect vectors of plant diseases. Plant pathogens are transmitted either via contact, or via contamination through soil or other biological agencies.

Majority of the plant diseases are transmitted by insects as well as by a few other arthropods like mites and only a small percentage by mechanical means or contamination of the soil. Insects possessing both piercing as well as sucking mouthparts and biting and chewing mouthparts are associated with transmission of disease. Majority of the insect vectors belong to the order Hemiptera (Aphids, Leafhoppers, Whiteflies and Mealy bugs), however, a few other insects belong to Thysanoptera (Thrips), Coleoptera (Beetles), Orthoptera (Grasshoppers) and Dermaptera (Earwigs). Homopteran insects alone are known to transmit about 90 per cent of the plant diseases.

The salient features of homopterans (aphids and leafhoppers), which make them efficient vectors are as follows:

- They make transitory however regular probes with their mouthparts into host plants.
- As the population density of these insects reaches a critical level, winged migratory individuals are produced.
- In several species, winged females deposit a few progenies on each of the many plants.
- These insects do not destroy entire plant during feeding and hence viruses need living cells for their survival as well as multiplication.

A large number of plant diseases caused by viruses, phytoplasmas, bacteria as well as fungi are transmitted by insects.

i. Viruses

A virus is a set of one or more nucleic acid molecules, normally encased in a protective coat or coats of protein or lipoprotein that is able to organize its own replication only within suitable host cells. It is ultramicroscopic in size and can be seen only with the aid of an electron microscope. From biological point of view, viruses cannot be classified either as living organisms or non-living. The reason being virus possess specific defining characteristic features of both living as well as non-living. Thus, to conclude, a virus is a non-cellular, infectious organism made up of genetic material and protein that can invade and reproduce only within the living cells of bacteria, plants and animals.

Viruses are non-cellular as they lack a cellular structure, and are compose of only the genetic material. Viruses are crystal-like structures when they are present outside the body of an organism, and becomes highly infectious and lethal when they enter a living cell. Viruses are inert outside a host cell, and then they are referred to as virions.

It is spherical or rod-shaped, nucleoproteinaceous (chief constituents being ribonucleic acid 5-35% and proteins 65-95% by weight) in composition and can live and multiply only in living cells. Viruses are responsible for many diseases in man (influenza, measles, mumps, polio, pox, etc.) and plants (mosaic, leaf curl, etc.).

Viruses contains either DeoxyRibonucleic Acid (DNA) or RiboNucleic Acid (RNA) with single or double strands as their genetic material. Viruses are classified on the basis of genetic material – dsDNA, dsRNA, ssDNA, ssRNA (orthomyxoviruses). Viruses can cause deadly diseases among animals as well as plants. Potato mosaic and tobacco mosaic are the common viral diseases among plants. Plant virus diseases have become more prevalent and destructive in recent years. This is mostly due to exchange of plant material from one region to other region which enables the spread of the virus to new areas, and distribution of many insect vectors in new regions in the world.

There are over 850 described plant virus species. About half of the insect vectors are aphids, a third are the leafhoppers. Mealy bugs and whiteflies transmit some viruses, and six are transmitted by thrips. The main aphid vectors are *Myzus persicae (Sulzer)*, *Aphis gossypii Glover* and *Aphis craccivora Koch*.

Additionally, Whitefly, *Bemisia tabaci* (Gennadius) as well as leafhoppers are also responsible for transmission of plant viruses. Whitefly mostly transmits mosaics and leaf curls in crops like pulses, vegetables as well as other crops like cotton, tobacco and papaya. It is responsible for causing huge economic loss. The leaf and planthoppers transmit tungro, yellow-orange leaf, grassy stunt and ragged stunt in rice.

Tomato spotted wilt is known to be transmitted by thrips. Mandibulate insects like grasshoppers, earwigs and chrysomelid beetles transmit turnip yellow mosaic. Several species of mites are also responsible for transmission of viruses of cereals and fruit crops. Table 1.2 below shows the list of important mite vectors of virus diseases of plants.

Table 1.2 *List of Important Mite Vectors of Virus Diseases of Plants*

S.No.	Mite vector	Virus	Host(s)
1.	*Abacarus hystrix* (Nalepa) (Acari : Eriophyidae)	Agropyron mosaic	Wheat, switch grass
2.	*Aceria ficus* (Corte) (Acari : Eriophyidae)	Fig mosaic	Fig
3.	*Aceria tulipae* (Keifer) (Acari : Eriophyidae)	Wheat streak mosaic	What, oats, barley, maize
4.	*Aculus fockeui* (Nalepa & Trouessart) (Acari : Eriophyidae)	Prunus necrotic ring spot	Plum, peach, cherry
5.	*Eriophyes inaequalis* Wilson & Oldfield (Acari : Eriophyidae)	Cherry leaf mottle	Sweet cherry
6.	*Eriophyes insidiosus* Keifer & Wilson (Acari : Eriophyidae)	Peach mosaic	Peach, nectarine

Source : Gillot (2005)

Types of Viruses

On the basis of the method of transmission and persistence in the vector, viruses may be classified into three categories, i.e., non-persistent viruses, semi-persistent viruses and persistent viruses discussed as follows:

Non-Persistent Viruses

Non-persistent viruses are those viruses which are believed to be transmitted as contaminants of the mouth parts. Such viruses are also called stylet-born viruses and the type of transmission is mechanical. The vector is able to acquire the virus from a disease source and transmit to a healthy plant by feeding for a few seconds.

These viruses do not persist longer within the insect vectors which can transmit them soon after feeding on infected plant but the ability to transmit fresh infection soon disappears after the insect feeds on healthy or immune plants. The efficiency of transmission of non-persistent virus is greatly affected by modifying the time of feeding and by starving the vectors before and after feeding. Aphids are the vectors of a great majority of such viruses which are carried only in their stylets.

The following are the main features of the non-persistent viruses:

- Vectors are optimally infective when they have fed for approximately 30 seconds on the infected plant.
- Transmission is improved if vector is starved for a period before an infection feed.
- If the vector is starved after an acquisition, it begins to lose ability to transmit within 2 minutes.
- After acquisition feeding, infectivity is rapidly lost when the vectors feed on healthy plants.

Semi-Persistent Viruses

Semi-persistent viruses are carried in the anterior regions of the gut of a vector, where they may multiply to a certain extent. Vectors do not normally remain infective after a molt, presumably because the viruses are lost when the foregut intima is shed. Several of the leafhopper transmitted viruses fall under this category.

Persistent Viruses

Persistent viruses are those that persist longer within the infective agent, i.e., vector. These viruses, when acquired by a vector, pass through the midgut wall to the salivary glands from where they can infect new hosts. In case of these viruses, the insect has to feed on the source of virus for comparatively longer periods.

The insect, after such acquisition of virus, becomes infective only after a certain period, ranging from several hours to 10-20 days, which is called the incubation period or latent period. Such viruses may multiply within tissues of a vector, which retains the ability to transmit the virus for several days and in some instances the rest of its life. Therefore, the vector need not feed on the virus source again and again to retain its infective capacity.

Thus, the vector insect feeds on the diseased plant (acquisition feed), requires some time after acquisition feed to transmit the virus (latent or incubation period), feeds on healthy plant (inoculation feed) and in the process transmits the virus acquired earlier. Such viruses are also called circulative or circulative-propagative viruses and the type of transmission as non-mechanical. Many of the leafhopper transmitted viruses belong to this category.

Mechanism of Transmission

For inoculation of virus into a plant by sucking insects, the puncture is initiated by a number of forward and backward movements of the inner pair of stylets. During the forward movements, the fluid flows into them, during the backward movements, saliva is ejected.

Generally, an insect injects by feeding on any part of the plant, but in some cases the virus is only found in the phloem and has to be injected into the phloem, the movement of which is perhaps controlled by the pH gradient between the mesophyll and the phloem. Some viruses are concentrated in the epidermal cells and others in the mesophyll or xylem.

The mandibulate insects like grasshoppers and beetles regurgitate during feeding. The regurgitated fluid containing the virus is brought into contact with the healthy plant, thus transmitting the virus.

Virus-Vector Relationship

Irrespective of the type of transmission, virus-vector relationship is highly specific. Generally, one type of virus disease is transmitted only by insects belonging to one particular group, i.e., mosaics by aphids and leaf curls by whiteflies. In case of leafhoppers, among 110 species known to be vectors, about 100 species transmit only one virus.

Similarly, there are viruses which are transmitted by a particular species of an insect and not by others of the same genus. For example, cabbage ring spot is transmitted only by *M. persicae* and not by *M. ornatus*. A vector can also acquire and transmit more than one virus to the respective hosts.

ii. Phytoplasmas

Phytoplasmas, originally known as mycoplasma-like organisms are non-culturable degenerate Gram-positive prokaryotes which are closely associated to mycoplasmas as well as spiroplasmas. Phytoplasmas lack a visible cell wall, whose place is taken by a thin elastic cytoplasmic membrane which cannot endure the osmotic pressure. Phytoplasmas are pleomorphic and may be spherical or oval in size, with size varying from 80 to 800µ in diameter.

Phytoplasmas are important insect-transmitted pathogenic agents causing more than 700 diseases in plants. The single most successful order of insect phytoplasma vectors is the Hemiptera. This group collectively possesses several characteristics that make its members efficient vectors of phytoplasmas.

- Hemipterans are hemimetabolous, hence, nymphs as well as adults feed similarly and are in the same physical location-usually both immatures as well as adults can transmit phytoplasmas.
- Hemipterans feed specifically and selectively on certain plant tissues, which makes them efficient vectors of pathogens residing in these tissues.
- Their feeding is non-destructive in nature, encouraging successful inoculation of the plant vascular system without damaging the conductive tissues and eliciting defensive responses.
- Hemipterans exhibit a propagative as well as persistent kind of relationship with phytoplasmas. They possess obligate symbiotic prokaryotes that are passed to the offspring by transovarial transmission, the same mechanisms that allow the transovarial transmission of phytoplasmas.

Mechanism of Transmission

Phytoplasmas are phloem-limited; hence, only phloem-feeding insects can possibly obtain and transmit the pathogen. Majority of the phytoplasma vectors belongs to the family Cicadellidae. Phloem-feeding insects obtain phytoplasmas passively during the process of feeding the phloem of infected plants. Table 1.3 shows important vectors of phytoplasma transmitted diseases.

Table 1.3 *List of Important Vectors of Phytoplasma-Transmitted Diseases*

S.No.	Insect vector	Mycoplasma(s)	Host(s)
1.	*Cestius phycitis* (Distant)(Hemiptera : Cicadellidae)	Brinjal little leaf	Brinjal
2.	*Macrosteles quadrilineatus* Forbes (Hemiptera : Cicadellidae)	Aster yellows	Aster, barley, carrot, celery, cucumber, wheat
3.	*Nephotettix nigropictus* (Stal), *N. virescens* (Distant) (Hemiptera : Cicadellidae)	Yellow dwarf	Rice
4.	*Orosius albicinctus* Distant (Hemiptera : Cicadellidae)	Sesame phyllody	Sesame
5.	*Recilia dorsalis* (Motschulsky) (Hemiptera : Cicadellidae)	Yellow dwarf	Rice
6.	*Scaphytopius acutus* (Say), *S. irroratus* (Orthoptera : Gryllotalpidae)	Aster yellows	Aster, barley, carrot, celery, cucumber, wheat
7.	*Stephanitis typica* (Distant) (Hemiptera : Tingidae)	Coconut root wilt	Coconut

Source : Modified after Gillot (2005)

Insects need to feed for a duration of few minutes to several hours to obtain enough titer (measurement of the amount or concentration of a substance in a solution) of phytoplasma. The longer the feeding period that is also known as the acquisition access period, the greater the chance of acquisition of disease-causing pathogen by insect. The time period that passes from initial acquisition to the ability to transmit the phytoplasmas (latent period or incubation period) is temperature dependent and varies from few to 80 days.

During the latent period, phytoplasmas move through and replicate in the vector's body. Phytoplasmas can pass intracellularly via the epithelial cells of the midgut and replicate within a vesicle or they can pass between two midgut cells and through the basement membrane to enter the haemocoel. Phytoplasmas circulate in the haemolymph, where they might infect other tissues like Malpighian tubules, fat bodies as well as brain or other reproductive structures. Phytoplasmas can be transmitted by insect vector only if they are able to penetrate specific cells of the salivary glands of the insects. It is necessary that very high levels of phytoplasmas must accumulate in posterior acinar cells of the salivary gland before they can be transmitted.

Vector-Phytoplasma Relationship

The interaction that takes place between the insects and phytoplasmas is complex and variable. The complex sequence of events which are necessary for an insect to obtain and consequently transmit phytoplasmas to plants indicates a very high degree of specificity of phytoplasmas to insects. However, several phytoplasmas are transmitted by a lot of different insect species.

In addition, a single vector species might transmit two or more phytoplasmas, and hence an individual insect vector can be infected with dual or multiple phytoplasma strains at the same time. Vector-host plant interactions also show a vital role in defining the transmission of phytoplasmas. Polyphagous vectors do have the possibility to inoculate a broader range of plant species, depending on the resistance to infection of each host plant.

For example, it has been observed that leafhoppers are unable to obtain phytoplasmas from different infected plant species. Chrysanthemum yellows (CY) phytoplasma is effectively transmitted by three leafhoppers, namely: *Euscelidius variegatus, Macrosteles quadripunctulatus* and *Euscelis incisus*. All three species of leafhoppers obtain from and transmit to CY-infected chrysanthemum and uninfected chrysanthemum, respectively.

However, only *Macrosteles quadripunctulatus* and *Euscelidius variegatus* get CY after feeding on CY-infected periwinkle and later on transmit CY to uninfected plants. None of the leafhoppers is known to acquire the phytoplasma from CY-infected celery, which is a dead-end host. Dead-end hosts refers to the plants which can be inoculated and later become infected with phytoplasmas, however, from which insects fails to get phytoplasma.

iii. Bacteria

Bacteria are microscopic organisms that can thrive well in diverse environments. Bacteria can be extremely useful for various commercial purpose as well as pathogenic too. Naked circular DNA is the genetic material in these organisms. A nuclear envelope is absent. Both, ribosomes as well as simple chromatophores, are the only subcellular organelles in the cytoplasm. The bacteria are surrounded by two protective coverings; the outer cell wall and the inner cell membrane. However, a few bacteria like Mycoplasma lack cell wall. A few bacteria are also covered by a capsule. Short whip-like appendages referred to as pili surround the surface of the bacteria which aids in carrying out sexual reproduction. The long whip-like structures are known as flagella. Of the total about 1800 known bacterial species, most are saprophytes living on dead plant or animal tissues or organic wastes. There are about 200 species of bacteria which are parasitic on plants and many of them consisting of numerous pathovars.

Bacteria possess both autotrophic as well as heterotrophic mode of nutrition. Autotrophic bacteria derive their nutrition from inorganic substances, i.e., like green plants they are capable of synthesizing organic food/substance from inorganic material. Heterotrophic bacteria depend entirely upon external organic materials as their source of food as they cannot synthesize their own food like autotrophic bacteria. The shape of the bacteria varies from spherical, rod-shaped, comma shaped, coiled to filamentous. A slimy capsule is present outside the cell wall in a large number of bacteria. These bacteria are referred to as capsulated bacteria or virulent bacteria. The major constituents of capsule are polysaccharides as well as the nitrogenous substances like amino acids.

For example, *Bacillus, Anthracite, Diplococcus pneumoniae, Mycobacterium tuberculosis* are capsulated bacteria. Bacterial cells are covered with a rigid cell wall composed of polysaccharides, proteins as well as lipids. We also find D-glutamic acid and diaminopimelic acid. Beneath the cell wall a thin, elastic, selectively permeable plasma membrane is present. Cytoplasm refers to the complex aqueous fluid or semifluid ground substance (matrix). It is granular in nature due to the presence of numerous ribosomes. Cytoplasm is composed of vitamins, salts, enzymes, carbohydrates, soluble proteins, co-enzymes, lipids, mineral and nucleic acids. All the organic matter is present in the colloidal state. Double-helical circular genetic material (DNA) of the bacteria is referred to as nucleoid. It has other common names like genophore, naked nucleus or incipient nucleus. Several bacteria contain extrachromosomal DNA in addition to nuclear DNA. These genetic elements are referred to as plasmids.

Plasmids are circular double stranded DNA molecules and sometimes contains essential genes responsible for conferring antibiotic resistance to bacteria. Flagella are fine, thread-like, protoplasmic appendages extending via the cell wall as well as the slime layer of the flagellated bacterial cells. Flagella aids bacteria to swim. Pilli are small hair like appendages or outgrowths present on the external cell surface of bacteria. Pilli are composed of special protein known as pilin protein. Pilli aids in sexual reproduction. Autotrophic bacteria are producers, i.e., they are able to produce their own food from inorganic substances like green plants. Majority of the bacteria are heterotrophic in nature, i.e., they cannot synthesize their own organic food. This class of heterotrophic bacteria depends upon external organic matter for their survival. Heterotrophic bacteria are of three types-: Parasites, Saprotrophs and Symbionts.

Plant bacterial diseases fall into three categories:

- Wilting, due to invasion of the vascular system or water-conducting vessels, for example, cucumber wilt.
- Necrotic blights, rots and leaf spots, where the parenchyma is killed, for example, fire blight.
- Hyperplasia or over growth, for example, crown gall.

Pathogenic bacteria cannot enter plants directly via unbroken cuticle however they get in through insect or other wounds, stomata, hydathodes, lenticels as well as flower nectaries. The role of insects in transmitting bacterial diseases has come in to attention when it was realized that the plant pathogenic bacteria are unable to penetrate plant tissue without a court of entry.

The insect pays through feeding as well as oviposition wounds, as a mechanical carrier of the organism on its body and in few situations, by advantage of a mutualistic relationship that exist between the organism and the insect which protects a continuing association among pathogen, insect and the host plant.

Several bacterial diseases of plants are known to be transmitted by insects (Refer Table 1.4). Fire blight of apple and pear, caused by *Erwinia amylovora* is carried by aphids, leafhoppers, etc. Potato blackleg, caused by *Erwinia carotowora*, is transmitted by seedcorn maggot, *Hylemyia cilicrura* (Rondani).

Table 1.4 List of Major Vectors of Bacterial Diseases of Crop Plants

S.No.	Insect vector	Disease	Host(s)
1.	*Chaetocnema pulicaria* (Meisheimer), *C. denticulata* (Coleoptera : Chrysomelidae)	Bacterial wilt (or Stewart's bacterial wilt)	Maize
2.	*Diabrotica duodecimpunctata* (Olivier), *D. vittata* (Coleoptera : Chrysomelidae)	Cucurbit wilt	Cucumber, muskmelon
3.	*Diaphorina citri* Kuwayama (Hemiptera : Aphalaridae)	Citrus canker	Citrus
4.	*Hylemya cilicrura* (Rondani), *H. trichodactyla* (Rondani) (Diptera : Anthomyiidae)	Potato blackleg	Potato
5.	Wide range of species of bees, wasps, flies, ants and aphids	Fire blight	Apple, pear, quince, etc.

Source : Modified after Gillot (2005)

iv. Fungi

Fungi are organisms having no chlorophyll, reproducing by sexual and asexual spores, not by fission like bacteria and typically possessing a mycelium or mass of interwoven threads (hyphae) containing well marked nuclei. There are about 4300 valid genera of fungi and about 70,000 species living as parasites or saprophytes on other organisms or their residues. More than 8,000 species are known to cause plant diseases.

There are several insects associated with the spread of fungal diseases (Refer Table 1.5). Many flies mechanically transmit the ergot of cereals caused by *Claviceps purpurea*. The ergot disease of bajra, caused by *Sphacelia microcephala*, is mechanically carried by insects that visit the flowers attracted by the sugary secretion found on the fungus infected earheads.

Table 1.5 List of Principal Vectors of Fungal Disease of Crop Plants

S.No.	Insect vector(s)	Disease	Host
1.	*Hylurgopinus rufipes* (Eichhoff) (Coleoptera : Scolytidae)	Dutch elm disease	Elm
2.	*Melanoplus differentialis* (Thomas) (Orthoptera : Acrididae)	Cotton wilt	Cotton
3.	*Scolytus multistriatus* (Marsham), *S. scolytus* (Fabricius) (Coleoptera : Scolytidae)	Dutch elm disease	Elm
4.	About 40 species of insects especially flies, beetles and aphids	Ergot of cereals	Cereals
5.	Several species of insect visiting flowers	Ergot of bajra	Bajra

Source : Modified after Gillot (2005)

The cotton wilt, caused by *Fusarium vasinfectum* (fungal plant pathogen), is transmitted through the faecel pellets of many grasshoppers like *Melanoplus differentialis* (Differential grasshopper), after they have fed upon infected plants. The common sooty mould fungus (*Capnodium* spp.) grows on the honeydew excreted by several homopteran insects like aphids, leafhoppers, mealy bugs, whiteflies, etc.

In Table 1.6 major bacterial and fungal diseases caused in mulberry are shown.

NOTES

Table 1.6 Major Bacterial and Fungal Diseases Caused in Mulberry

Name of disease	Bacteria/fungus	Causative agent
Fungal leaf spot	Fungus	*Cercopora moricola*
Powdery mildew	Fungus	*Phyllactinia corylea*
Mulberry rust	Fungus	*Cerotelium fici*
Fungal leaf blight	Fungus	*Alternaria alternate* *Fusarium palledoroseum, F. solani* *Helminthosporium* spp. *Colletorotrichium* spp.
Bud blight	Fungus	*Fusarium laeritium* f.sp. *mori*
Bacterial blight	Bacteria	*Pseudomonas syringae* pv. *mori*
Bacterial leaf spot	Bacteria	*Xanthomonas compestris* pv. *mori*
Bacterial wilt	Bacteria	*Pseudomonas solanacearum*
Root rot	Fungus	*Fusarium solani* *F. oxysporum*
Stem canker	Fungus	*Botryodiplodia theobromae*
Cutting rot	Fungus	*Fusarium solani*
Collar rot	Fungus	*Phoma mororum*
Die-back	Fungus	*Botryodiplodia theobromae*

Check Your Progress

10. What are the insect vectors of plant diseases and how are they transmitted?
11. List some of the salient features of homopterans.
12. Name the common viral diseases among plants.

1.6 INSECTS IN THE SERVICE OF FORENSIC SCIENCES

Forensic entomology refers to the scientific study of the invasion of the succession pattern of arthropods with their developmental stages of different species found on the decomposed cadavers during legal investigations. Forensic entomology refers to the branch of forensic science that deals with the study of insects for forensic analysis. Forensic entomology employs arthropods, including insects, arachnids, centipedes, millipedes and crustaceans to criminal or legal cases. This plays a significant role in the investigation of deaths as well as other criminal matters, however, it can also be used to detect drugs and poisons, to determine the location of an incident as well as to find the presence and time of the infliction of wounds.

Three official definitions of forensic entomology are as follows:

1. 'Forensic entomology is the study of insects for medico-legal purposes' - SFU Museum.
2. 'Forensic entomology is the study of insects/arthropods in criminal investigation' - NCBI.
3. 'The study of life cycles of insects that feed on the flesh of the dead, to establish time of death and occasionally identify chemicals present in a person's body at the time of death' - The Free Dictionary by Farlex.

Insects Used in Forensic Entomology

This section discuss the way insects are used in forensic entomology:

i. Flies: Flies are among the first insects that are attracted to a corpse. Their offspring, maggots, feed on moist cadavers. Following are the flies that are relevant to forensic entomology:

- **Blow Flies:** The earliest known case of a crime being solved using insect (blow flies). Blow flies are naturally attracted to the soft tissues, blood, and bones of dead bodies. The flies could sense the residue of blood and tissue from up to 16 km away.
- **Flesh Flies:** Flesh flies are mostly seen breeding on dead and decaying corpses, garbage, dung or any other decaying material. A few species of flesh flies are reported to lay their eggs on the exposed wounds of mammals.
- **House Flies:** House flies are the most common type of flies and are the carriers of serious diseases.
- **Cheese Flies:** Cheese flies are mostly observed on animal products as well as fungi. The larvae of cheese flies mostly infest smoked fish, cured meat, cheese and decaying animals. The presence of cheese fly larvae is critical for approximating the time of death for human beings.

ii. Beetles: Beetles generally infest a cadaver (dead body) in the later stages of decomposition when compared to flies. Beetles are replaced by moth flies in drier conditions.

- **Dermestid Beetles:** Dermestid beetles are also known as skin or hide beetles. Dermestid beetles infest a dead and decomposing cadaver only after all the soft tissues have been consumed by other organisms (scavengers). They flourish on the skin and hair. These are the commonest insects collected by forensic entomologists from dead bodies of human beings.
- **Bone Beetles:** Bone beetles are also collected from corpses in the later stages of decomposition. Beetles belonging to this family (Cleridae) feed on decaying flesh.
- **Carrion Beetles:** The larva of carrion beetles are known to thrive on vertebrate carcasses while the adults devour maggots. These chaps are quite a patron of social service as they have a tendency to dig and inter small carcasses underground.
- **Hide Beetles:** Hide beetles feed on dead and decaying bodies as well on dry animal products like cheese, bacon, dog treats, dried fish, etc. These flies clustered around/resources where feeding and mating are likely to happen.
- **Rove Beetles:** Rove beetles are different from carrion beetles in a way that they feed on cadavers or carcasses and not on decaying flesh (carrion). They thrive on maggots and other insect larvae present on carrions.

- **Scarab Beetles:** Scarab beetles belong to the Scarabaeidae family that also includes dung beetles which are generally found on or under carrion and corpses. They feed on fungi, dung or decaying flesh and act as a cleanup crew for the animal kingdom.
- **Sap Beetles:** Sap beetles are found near fermenting or decaying plant fluids like rotting melons or tree sap. A few sap beetles are known to infest dead bodies and are significant in forensic entomology.
- **Clown Beetles:** Clown beetles are also known as Hister beetles. They usually hide under the carcass during the day to emerge at night and feed on maggots or dermestid beetle larvae thriving on it.
- **Dung Beetles:** Dung beetles survive on manure, decaying fungi and the decaying flesh of dead animals at any stage of the decomposition.
- **Mites:** Macrocheles mites feed on corpses during the early stages of its decomposition whereas Tyroglyphidae as well as Oribatidae mites flourish on dry skin produced later in the process of decomposition
- **Moths:** The larvae of moths feed on the hair of mammalian corpses and they are known to be the last animals carrying out the decomposition of a corpse.

Other Application of Forensic Entomology

- **Food Infestation Cases:** Food production facilities where Integrated Pest Management procedures are not followed can be quite enticing for pests. Cases involving the contamination of food products with insect debris call for the involvement of a forensic entomologist to investigate and provide litigation support.
- **Presence of Drugs:** An analysis of the bodies, fecal matter as well as dead skins of insects feeding on flesh and cadavers helps forensic entomologist to determine the presence as well as type of drugs or poison present in the body.
- **DNA Extraction:** Blood-sucking insects consume blood that can be used by a forensic science expert for extraction of DNA. For example, if there is a blood-sucking insect, then the scientists can extract DNA from the insect to see who's DNA it is.

Check Your Progress

13. Define the term forensic entomology.
14. What does forensic entomology employs?
15. Write about the flies that are relevant to forensic entomology.

1.7 WOODBORING BEETLES: LIFE HISTORY AND CONTROL MEASURES

NOTES

Beetles are insects that belongs to the order Coleoptera in the superorder Endopterygota. The front pair of wings of beetles are hardened into wing-cases, elytra, differentiating them from majority of other insects. The Coleoptera, with approximately 400,000 described species, is the largest of all orders, comprising approximately 40% of described insects and 25% of all known animal life-forms; new species are discovered often, with studies suggesting that there are between 0.9 to 2.1 million total species. The general anatomy of a beetle is fairly uniform and typical of insects, even though, there are numerous examples of uniqueness, like adaptations in water beetles which trap air bubbles under the elytra for use while diving. Beetles are endopterygotes (wings develop internally), it means that they undergo complete metamorphosis, with a series of noticeable and comparatively abrupt changes in body structure between hatching and becoming adult after a relatively immobile pupal stage. A few beetles like stag beetles, have a marked sexual dimorphism, i.e., males are different from the females morphologically, the males having extremely enlarged mandibles which they use to fight with other males. Several beetles are aposematic, with bright colours as well as patterns warning of their toxicity, while others are harmless.

Wood boring insects refer to a selection of arthropods which cause damage to wooden structures. This group of insects feature a range of species of insect at different stages of their life cycles from larvae to adults.

Wood boring insects are seen as pests due to the damage they create in both urban, and rural areas. Within an urban environment wood boring insects can cause a huge amount of damage to residential properties. Whilst in agricultural and rural settings, wood boring insects are responsible for damaging crops. However, it’s worth noting that some wood boring insects are a key part to the ecosystem, helping to recycle dead trees. There are some cases though where wood boring insects have become an epidemic in some forests killing a large amount of trees.

The larval stages of these wood beetles which can cause most of the damage, are usually referred to as woodworms. The families of the longhorn beetles, bark beetles as well as weevils, and metallic flat borers are the richest in species. While humans perceive these insects as a useless nuisance, they actually play an essential role in forest ecology. Wood beetles generally feast on dead and decaying trees, they act as primary decomposers of trees as well as recyclers of the comparatively hard to decay wood matter. There are several types of beetles that damage wood used for different construction purposes like furniture, building, etc. As it is the larval form which is responsible for causing maximum damage, hence they are also referred to as wood worms. Woodboring beetles falls into five scientific families namely: *Lyctidae, Bostrichidae, Anobiidae, Cerambycidae* and *Buprestidae*. A majority of the species are less than 6mm (1/4 inch) long, however, a few reach 25 mm (1 inch) in length (Refer Figure 1.27).

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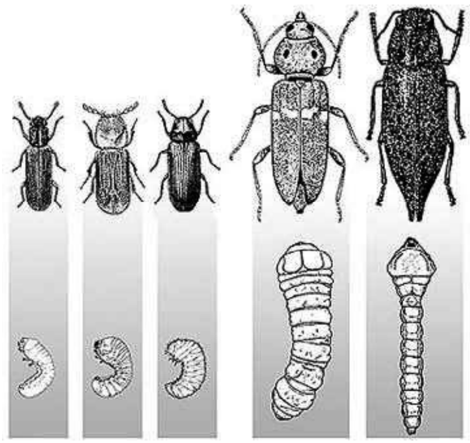

Fig. 1.27 Wood-Damaging Beetles

In above Fig. 1.27 wood-damaging beetles are shown, where adults, have been shown at the top followed by the larvae at bottom. Left to right: *Lyctid, Bostrichid, Anobiid, Cerambycid (old house borer)* and *Buprestid.*

Life Cycle of Woodboring Beetles

Young beetle larvae hatch from eggs, burrow into wood, and begin feeding. The difference in characteristics features of larvae from different species of wood-boring beetle have been specified in Table 1.7 below. The larvae of different species of woodboring beetles differ in size as well as shape, but majority of the larvae are yellowish white in colour with dark mandibles (jaws). The strong jaws of the larva enable it to construct tunnels as they feed on starch as well as other compounds present within the wood. Wood-damaging beetle larvae often go unnoticed because they feed beneath the surface of the wood and their tunnels are not visible. Feeding tunnels vary in size and shape according to species, and can be distinguished from other types of insect damage, for example termites and carpenter ants. The time required for the larvae to complete their development varies from a few months to several years, depending on the species and the availability of food and moisture in the wood (Refer Figure 1.28).

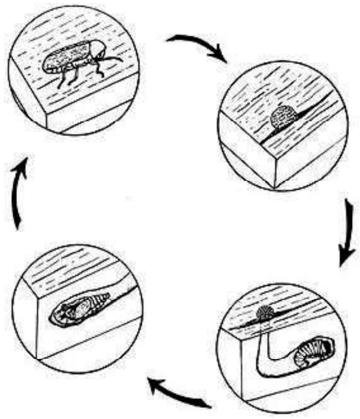

Fig. 1.28 *Wood-Damaging Beetles Spend Most of Their Life Cycle in the Larval Stage, in Which the Damage Occurs*

When beetle larvae have completed their development inside the wood, they pupate. The pupal stage is an inactive developmental period. The pupae finally change into adult beetles that bore holes to the outside of the wood. The size and shape of these exit holes vary between species. Soon after emerging from the wood, adult beetles mate and the newly mated females search for suitable sources of wood in which to lay their eggs. The female often tastes the wood to determine whether suitable levels of starch and moisture exist. Some groups of beetles prefer hardwoods while others prefer softwoods. Most wood-boring species lay eggs only on wood before it is seasoned and processed, but a few species will lay eggs on seasoned lumber.

Table 1.7 *Characteristics of Wood-Damaging Beetles*

Beetle Family	Adult Appearance	Wood Preferences	Characteristic Damage
Lyctidae True powderpost beetles	**Shape** Somewhat flattened, head projecting forward. **Size** 3 to 7 mm long. **Colour** Reddish brown to black.	Hardwoods Sapwood Prefer newer lumber Will reinfest	**Exit Holes** 0.8 to 1.6 mm in diameter. Early damage along the grain of the wood but later may reduce entire sapwood to powder. **Frass** Fine powder that readily sifts out. No pellets.
Bostrichidae False powderpost beetles	**Shape** Cylindrical, head directed downward, covered by spiney thorax. **Size** 3 to 6 mm long. **Colour** Reddish brown to black.	Hardwoods Sapwood Will occasionally attack softwoods Rarely reinfests	**Exit Holes** 3 to 7 mm in diameter. Occasional tunnel going across the grain. **Frass** Fine or coarse, which tends to cake. Few, if any, pellets.
Anobiidae Furniture beetles	**Shape** Cylindrical, head directed downward and covered by hood like thorax. **Size** 3 to 7 mm long. **Colour** Reddish brown to black.	Hardwoods Softwoods Sapwood Heartwood Seasoned wood Will reinfest	**Exit Holes** 1.6 to 3.0 mm in diameter. More advanced galleries running across the grain. **Frass** Contains elongate or bun-shaped pellets.
Cerambycidae Longhorned beetles (old house borer)	**Shape** Somewhat flattened, antennae half the length of the body. **Size** 16 to 25 mm long. **Colour** Greyish black to	Softwoods Sapwood Seasoned wood Contrary to its name, it prefers newer wood but may be found in	**Exit Holes** 6 to 10 mm in diameter. Extensive tunnels by larvae that avoid feeding all the way out to external surfaces. **Frass** Powder like, containing

Woodworm

Woodworm is a generic term used for a number of species of woodboring beetle and refers to the larvae of the beetles, which feed on wood after hatching from the egg, creating tunnels in the process. They only emerge from the timber after pupating and developing into adults, creating the characteristic holes in the wood surface.

This characteristic also leads to the misconception that the holes can be treated with insecticide to kill the beetle, when in fact it is pointless as the hole signifies that the beetle has left.

The main beetles that cause damage to structural timber and wooden fittings, furniture and items in buildings are classified into three groups, commonly called: Deathwatch (Anobiidae family), Powderpost and False powderpost beetles (Bostrichidae family).

Types of Woodworm (Life Cycle)

Following are the types of woodworms:

1. Common Furniture Beetle (*Anobium punctatum*)

The adults of common furniture beetle do not feed on wood, they only reproduce. Damage is majorly caused by their larval forms, which are also known as woodworm. The adults are 2.7–4.5 mm in length, whereas larvae are 1mm in length, C-shaped and creamy white in colour. The life cycle of the common furniture beetle is approximately 3–4 years long and due to that fact, evidence of infestation holes might take years to manifest (Refer Figure 1.29).

The common furniture woodworm attacks only seasoned sapwood timber. Generally, it does not attack heartwood timbers. Because of their love for sapwood, few building regulations declare that more than 25% of sapwood should not be used, so that building's structure could not be substantially damaged.

Life Cycle

Adult insects emerge between the month of May to August and then mate. Adult females lay eggs in cracks, crevices, end grain, old exit holes etc. Eggs are white in colour and shaped like a lemon. Larvae on emerging out from the eggs begins feeding on wood straight from egg for a continuous period of three or more years. Larvae reach up to 6mm in length. Development takes below surface of wood. They emerge in the pupal stage, which takes between 6–8 weeks.

Woodworm Signs

The sign of infestation by common furniture beetle includes round exit holes, approximately 1.5–2 mm in diameter. Short tunnels, lemon-shaped pellets present in gritty bore dust.

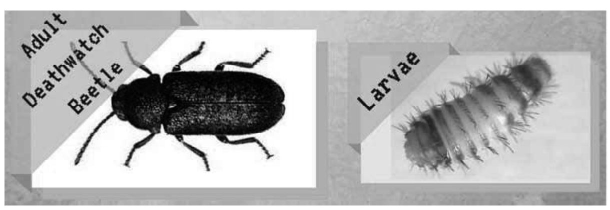

Fig. 1.29 *Adult and Larval Stages of Common Furniture Beetle*

2. Death-Watch Beetle (*Xestobium rufuvillosum*)

The larvae of the death-watch beetle prefer to chew on sapwood as well as heartwood of hardwoods, generally oak, which is partly decayed or damp. The adult beetle is 7mm in length, while its larvae is up to 11mm long. The common name of this wood-boring insect comes from the ticking/banging sound that the male makes while banging his head against the wood, in order to attract females. Hence, the mating call can be heard in a quiet infested house (Refer Figure 1.30).

Life Cycle

The adults of the death watch beetle appear between the months of March to June and lay their white in colour, lemon-shaped eggs approximately 20 days after mating. They prefer cracks as well as crevices for the purpose. The larvae crawl inside the wood prior to boring it and then continue to feed on it and grow for up to 12–14 years. In the pupa stage, these adults develop below wood surface around July–August, however, pre-emergent adults will wait in pupa chamber until the arrival of next year. They can usually be found on or beneath infested material during this emergence period as they require high temperatures to fly.

Woodworm Signs

Exit holes are round around 3mm in diameter. These woodworms bore extensive tunnels towards the centre of wood, due to this sometimes the damages are much more extensive than they appear on the outside. Bore dust in bun-shaped and contains pellets that are visible to the naked eye.

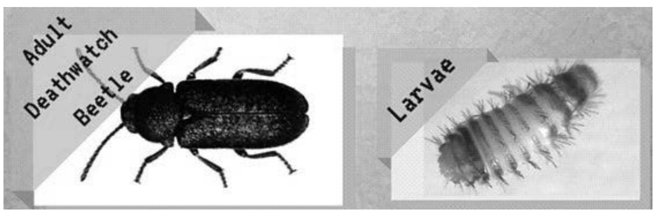

Fig. 1.30 *Adult and Larval Stages of Common Death Watch Beetle*

3. Ambrosia Beetle (*Platypodinae, Scolytinae*)

Ambrosia beetles belongs to the weevil subfamilies of *Platypodinae* and *Scolytinae*, which live in symbiotic association with ambrosia fungi. Ambrosia beetles are well known to attack dead trees or freshly cut logs situated in the forests. Unlike majority of the wood-boring insects, Ambrosia adults do the tunnelling in which they release spores as well as other cultivate fungal gardens, which is their only source of nutrition (Refer Figure 1.31).

NOTES

The fungus is responsible for causing major damages, as it penetrates wood tissue, digests it, and concentrates its nutrients on as well as near to the surface of the beetle gallery. Ambrosia insects generally live off sapwood and/or heartwood of dying or freshly dead trees. These beetles cannot infest seasoned timber and they do not need any kind of treatment.

Life Cycle

Varies according to the exact species of Ambrosia beetles.

Woodworm Signs

Surface of tunnels are coloured black or blue-black. Holes vary in size depending on the species, but the majority run across the grain in long distances. There's no bore dust.

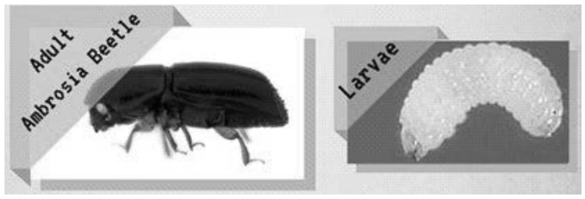

Fig. 1.31 *Adult and Larval Stages of Ambrosia Beetle*

4. Old House Borer Beetle (*Hylotrupes bajulus*)

Old house borers, also commonly known as house longhorn beetle. They belong to a species of wood-boring beetles from the family Cerambycidae (longhorn beetles) and are characteristic due to their habit of re-infesting the same wooden material from which they have emerged. The colour of these beetles varies from brown to black in colour, they are covered with grayish hair on the upper side of their bodies and have shiny spots that closely resemble eyes.

These beetles are usually found in new houses as it is quite probable because new home constructions may be using wood infected with the beetle's eggs, which can be explained by the fact that these new house beetles look for higher resin content that is found in wood less than 10 years old. Old house borers prefer new softwoods, particularly pine.

Larvae of this beetle is highly dangerous and can take up to 30 years to become adults, depending on the moisture content of the wood as well as the environment. They create severe tunnellings that can lead to structural collapse if not caught early (Refer Figure 1.32).

Fig. 1.32 *Longhorn Beetle*

NOTES

Life Cycle

Adult beetles emerge (and are most active) around July–September. In this period, they lay up to 200 white spindle-shaped eggs in a fan-shaped pattern in cracks of wood. Larvae feed on sapwood usually for more than four years, causing extensive damage and reaching up to 30mm in length. Pupal stage takes about 3 weeks before emerging as an adult.

Woodworm Signs

Large oval exit holes, around 6–10 mm in diameter, leaving course powdery frass around the whole vicinity. Tunnels may not be individually identifiable and have ridges on the surface. Internal damage is more severe than external in most cases.

5. Powderpost Beetle (*Lyctus brunneus*)

Powderpost beetles are a group of 70 species of wood-boring beetles which belong to the family Lyctinae. They comprises of one superfamily (Bostrichoidea) along with the common furniture beetles, death-watch beetles, spider beetles, as well as others (Refer Figure 1.33).

The name of the powder post beetle originates from the fact that their larvae feed on wood, and if not caught on time, they can turn what once was wood into a mass of fine powder. Thus being considered notorious pests. The larvae of powder post beetle are white in colour, C-shaped and do not attack wood older than 15 years.

Depending on the basis of species, the powder post beetle prefers hardwood or sapwood, however, one thing is sure: that they majorly chew on high starch content material. Items that can be infested comprises of tools or tool handles, furniture, books, toys, bamboo, frames, flooring, as well as structural timbers.

Life Cycle

The life cycle of powderpost beetle takes approximately 1–2 years outdoors and 8–10 months indoors. Adults emerge in the month from July to August when outdoors, if indoors they emerge any time. The eggs laid by the adults are white in colour, elongated with tail, eggs inside open vessels. Hatching takes approximately 2–3 weeks. Larvae feed and bore along the grain in the beginning. In the pupal stage, they tend to look white, more like a beetle less than a larva.

Woodworm Signs

The major sign of infestation by powder post beetle is the presence of tunnels that are filled with loose flour-like dust. Exit holes (which are commonly known as shot holes) are approximately1–3 mm in length in diameter (depending on the species) and are usually mistaken for common furniture beetle.

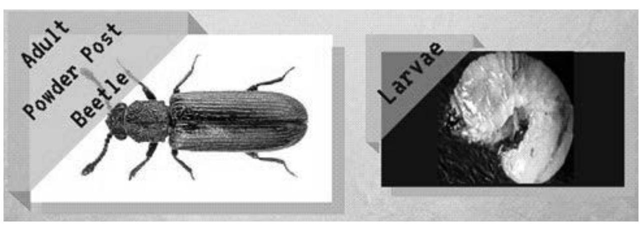

Fig. 1.33 Adult and Larval Stages of Powderpost Beetle

6. Woodboring Weevil (*Pentarthrum huttoni, Euophryum confine*)

Woodboring beetles belongs to the Curculionidae family of true weevils or snout beetles. It is the third-largest animal family with approximately 40, 000 species (also includes the ambrosia beetle). The wood-boring weevils are recognised by their characteristic long snout as well as antennae with small clubs.

The size of the adults varies from 1 to 40 mm in length. They can attack any wood that is decayed and prefer it damp (like the Pentarthrum huttoni beetle needs 100% humidity). Damage is caused by both larvae as well as adults stages, both of which are present in the infested area (Refer Figure 1.34).

Fig. 1.34 Woodboring Weevil

Life Cycle

Adults live up to a period of 16 months, feeding on wood along with larvae. Adults lay their white eggs on the surface or just below it. The larvae are curved in shape, white in colour, and bore widely along the grain for approximately 8–9 months. Pupa develops right below the surface.

Woodworm Signs

The major sign of infestation of woodboring weevil is the presence of tunnels along the grain often exposed or just below the surface. Exit holes are round but with ragged edges. Coarse bore dust with a 'gritty' feel is present. The damage of these insects always occurs along with fungal decay, which in most cases is the primary concern and more damaging.

Factors Affecting the Infestation by Woodboring Beetles

There are factors that can increase the chances of infestation by woodworm:

- Woodboring beetles can fly. Even though, their flight is restricted to some extent however still enough to fly through open windows, as any other bug would do.
- Bigger risk of acquiring these pests is old or second-hand furniture. It is due to the fact that previously used furniture in an infested household or stored in a place with other potentially infested furniture. To lower these chances, inspect closely any furniture that goes in your property.
- High humidity also contributes to infestation by furniture beetles.
- Wood infested with wood-boring beetles has numerous shot holes in the surface. Small pieces of sawdust (frass) produced by the larvae as they tunnel may shift from the holes when the wood is bumped or disturbed.
- Cutting into the infested wood usually reveals several tunnels filled with frass. Characteristics of the frass and the tunnel system vary between different wood-boring beetle species.
- Subflooring, hardwood flooring, interior trim, joists, sills and particularly beams are subject to attack. Other wood products, like hardwood furniture, implement handles as well as ladders, may also be attacked. Log houses are particularly vulnerable. Vacation or recreation structures are also more susceptible to beetle attack as they usually contain higher moisture content in the wood due to intermittent heating or poor ventilation.
- The amount of damage which is caused by woodboring beetles will vary based on the species of beetle as well as their unique feeding and egg-laying preferences.
- Damage weakens structural timbers and results primarily from the feeding activities of the beetle larvae.

Control of Wood boring Beetles

Prevention

Prevention is the best way to control infestation by wood beetles, however, it is not always easy due to hidden feeding activities of the larvae. However, once can lessen down the threat of infestation by using seasoned lumber in construction and inspecting lumber as well as other wood items before purchasing it for construction purpose. Other preventive step could be sealing off the exposed wood surfaces with the help of a protective layer of polyurethane, varnish, or paint. It will prevent the egg-laying activities of species that can reinfest structural timbers. Additionally, firewood should be de-barked, stored outside, and only brought into the home immediately before use.

Reducing the moisture content in structural wood also helps to prevent wood-boring beetle infestations. Good ventilation in attics as well as crawlspaces, in addition to constant heating and cooling, will maintain wood moisture levels below that required for growth and development of beetle larvae.

NOTES

Non-Chemical Control

Non-chemical control involves using heat as an effective mode of controlling populations of wood-boring beetles. The temperature of the wood must be maintained at 120 degrees Fahrenheit for at least 30 minutes to kill all of the active stages.

Chemical Control

It is possible to treat infestations in unfinished wood with an insecticide (Refer Table 1.8). Application of insecticide on unfinished wood can prevent its infestation in future. Insecticides must be applied as coarse sprays, or with a paintbrush. A second application of insecticide is must before the first is completely dry. This works out to be approximately 1 gallon of finished solution per 100 square feet of wood surface. Since the insecticide penetrates only on the outer surface, this type of treatment is intended to kill adults as they emerge from the wood, rather than the larvae form that are feeding within the wood.

Finished wood can also be treated, however, to do so, one need to remove the finish, treat the wood as mentioned above, and then refinish. However, it is expensive and always not possible to treat the finished wood in the way explained above, in this situation, it is often recommended to remove the finish, treat the existing exit holes, open joints as well as crevices present between boards with the help of an insecticide. A hypodermic needle is useful for slowly injecting diluted insecticide into the exit holes. When treating cracks, crevices as well as exit holes, repeated applications should be made over a period of several days.

A pest control professional can also be helpful in controlling infestations of wood-boring beetles in case of severe infestation. However, this entire process is very expensive. The pest control operator may be able to place smaller items, like pieces of furniture, in a fumigation chamber at a more reasonable cost. Fumigants available to the PCO for this purpose include methyl bromide as well as sulfuryl fluoride.

Table 1.8 *Insecticides for Controlling Wood-Damaging Beetles*

Insecticide	**Trade Name(s)**
Non-restricted-use insecticides*	
Disodium octaborate tetrahydrate	Bora-Care Tim-Bor
Restricted-use insecticides*	
Cyfluthrin	Tempo
Cypermethrin	Demon TC
Esfenvalerate	Conquer
Permethrin	Prelude

Check Your Progress

16. How are beetles different from majority of other insects?
17. What are woodboring insects?
18. Name the main beetles that cause damage to structural timber and wooden fittings.

1.8 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Arthropods are members of the Phylum Arthropoda. The word Arthropoda comes from two Greek words *arthron* and *podos*, where *arthron* means 'joint', and *podos* means 'foot', which together mean 'jointed feet'.
2. Head of insects contains the following parts:
   - One pair of antennae:
     - The antennae are usually used as tactile organs (organs pertaining to the sense of touch).
     - They can also be used as olfactory organs (organs of smell).
   - Eyes:
   - Most insects possess one pair of compound eyes and sometimes some simple eyes called 'ocelli'.
   - Mouthparts:
     - There is a big variety in types of mouthparts; biting, sucking, stinging, licking, etc.
3. Five orders of insects are as follows:
   - Order 1: Thysanura, for example Bristle tails, Silverfish.
   - Order 2: Diplura, for example two pronged Bristle tails.
   - Order 3: Protura, for example Proturans.
   - Order 4: Collembola, for example Spring tails.
   - Order 5: Ephemeroptera, for example Mayflies.
4. Pathogenic insects are those insects that acts as an intermediate or alternative host for a pathogenic organism like bacteria, virus or fungi and transmits them to a susceptible host.
5. A vector is referred to as an organism that acts as an intermediate or alternative host for a pathogenic organism and transmits them to a susceptible host. Thus, vectors are nothing but vehicles by which the parasites are transmitted from one host to another, i.e., the animal that acts as a carrier of disease producing germs (parasites) for transmission of disease from one host to another host.
6. When the disease-agent (parasite) undergoes multiplication or some developmental changes in vector host then such transmission is known as biological transmission.
7. Entomologists collects insects for variety of reasons. The collection of insects helps to identify and research the specialty of pests. It helps to educate people regarding different types of disease-causing insects as few insects spread diseases like malaria, etc.
8. Collection event of insects comprises of the following:
   - Collection as well as preservation of insect.

- Information regarding the insect sample like name of the collector, date of collection, locality from where insect is collected, habitat/food source of collection.

9. There are several devices and equipment's which are used for collecting insects, i.e., as follows:
   - Insect nets (aerial netting and sweep netting)
   - Collecting jars and bags
   - Aspirator
   - Collection kit
   - Beating sheet
   - Collecting container
10. The insects, besides directly damaging the crops, sometimes become responsible for the spread of pathogens in plants. All those insects which acquire the disease-causing organisms by feeding on the diseased plants, or by contact and transmit them to healthy plants are known as insect vectors of plant diseases**.** Plant pathogens are transmitted either via contact, or via contamination through soil or other biological agencies.
11. The salient features of homopterans (aphids and leafhoppers), which make them efficient vectors are as follows:
    - They make transitory however regular probes with their mouthparts into host plants.
    - As the population density of these insects reaches a critical level, winged migratory individuals are produced.
    - In several species, winged females deposit a few progenies on each of the many plants.
    - These insects do not destroy entire plant during feeding and hence viruses need living cells for their survival as well as multiplication.
12. Potato mosaic and tobacco mosaic are the common viral diseases among plants.
13. Forensic entomology refers to the scientific study of the invasion of the succession pattern of arthropods with their developmental stages of different species found on the decomposed cadavers during legal investigations.
14. Forensic entomology employs arthropods, including insects, arachnids, centipedes, millipedes and crustaceans to criminal or legal cases. This plays a significant role in the investigation of deaths as well as other criminal matters, however, it can also be used to detect drugs and poisons, to determine the location of an incident as well as to find the presence and time of the infliction of wounds.
15. Following are the flies that are relevant to forensic entomology:
    - Blow Flies: The earliest known case of a crime being solved using insect (blow flies). Blow flies are naturally attracted to the soft tissues, blood, and bones of dead bodies. The flies could sense the residue of blood and tissue from up to 16 km away.

- Flesh Flies: Flesh flies are mostly seen breeding on dead and decaying corpses, garbage, dung or any other decaying material. A few species of flesh flies are reported to lay their eggs on the exposed wounds of mammals.
- House Flies: They are the most common type of flies and are the carriers of serious diseases.
- Cheese Flies: Cheese flies are mostly observed on animal products as well as fungi. The larvae of cheese flies mostly infest smoked fish, cured meat, cheese and decaying animals. The presence of cheese fly larvae is critical for approximating the time of death for human beings.

16. Beetles are insects that belongs to the order Coleoptera in the superorder Endopterygota. The front pair of wings of beetles are hardened into wing-cases, elytra, differentiating them from majority of other insects.
17. Woodboring insects refer to a selection of arthropods which cause damage to wooden structures. This group of insects feature a range of species of insect at different stages of their life cycles from larvae to adults.
18. The main beetles that cause damage to structural timber and wooden fittings, furniture and items in buildings are classified into three groups, commonly called: Deathwatch (Anobiidae family), Powderpost and False powderpost beetles (Bostrichidae family).

1.9 SUMMARY

- Arthropods are members of the Phylum Arthropoda. The word Arthropoda comes from two Greek words *arthron* and *podos*, where *arthron* means 'joint', and *podos* means 'foot', which together mean 'jointed feet'.
- All the arthropods have jointed appendages which gives them a broad range of controlled and coordinated motions.
- Metamorphosis in subclass pterygota either insufficient without a pupal phase (incomplete metamorphosis) or total with a pupal stage (complete metamorphosis).
- Insects in Exopterygota group undergo a simple or incomplete metamorphosis called Hemimetabola.
- The silverfish and firebrats are found in the order Thysanura. They are wingless insects often found in people's attics, and have a lifespan of several years.
- Diplurans are the most primitive insect species, with no eyes or wings.
- The stoneflies of order Plecoptera are aquatic and undergo incomplete metamorphosis. The nymphs live under rocks in well flowing streams.
- Families belonging to the order Orthoptera are Acrididae, Meconematidae, Tetrigidae and Tettigoniidae.
- The webspinners have silk glands in their front legs and weave nests under leaf litter and in tunnels where they live.

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- Termites feed on wood and are important decomposers in forest ecosystems.
- Biting lice are ectoparasites that feed on birds and some mammals. There are an estimated 3,000 species in the order Mallophaga, all of which undergo incomplete metamorphosis.
- Strepsiptera undergo complete metamorphosis and pupate within the host insect's body.
- The butterflies and moths of the order Lepidoptera comprise the second largest group in the class Insecta. These well-known insects have scaly wings with interesting colors and patterns.
- Caddisflies are nocturnal as adults and aquatic when immature. The caddisfly adults have silky hairs on their wings and body, which is key to identifying a Trichoptera member.
- The order Hymenoptera includes many of the most common insects - ants, bees and wasps.
- Pathogenic insects are those insects that acts as an intermediate or alternative host for a pathogenic organism like bacteria, virus or fungi and transmits them to a susceptible host.
- A vector is referred to as an organism that acts as an intermediate or alternative host for a pathogenic organism and transmits them to a susceptible host.
- Biological vectors are those organisms (invertebrate animals like insects) in which the disease agents or disease-causing microorganisms increase their numbers either by multiplication or transformation.
- Aedes is a genus of mosquitoes originally found in tropical and subtropical zones, but now found on all continents except Antarctica.
- *Aedes* mosquitoes are visually distinctive because they have noticeable black and white markings on their bodies and legs.
- *Aedes aegypti*, the yellow fever mosquito, is a mosquito that can transmit dengue fever, chikungunya, Zika fever, Mayaro, yellow fever viruses, as well as other disease-causing agents.
- *Glossina Palpalis* (Tsetse fly) flies belongs to genus *Glossina* are obligate haematophagous insects, i.e., both male as well as female flies survive purely on blood diet.
- Mechanical vectors are those organisms where the disease-causing agent or parasites (germs) are attached to the outside of their body, like in legs and thus transmit the germs or parasites from one host to another without involving any developmental stages of the parasites in their body.
- *Musca domestica*, commonly known as the housefly has been seen commonly by people everywhere except for those living in the poles. The life cycle of housefly is nearly similar to that of other insects.
- *Periplaneta americana* (American cockroach) is one of the large-sized insects. They are also commonly known as waterbugs in certain parts of the world. These are some of the oldest insects whose fossils are 320 million years old.
- Infectious diseases spread from infected person to healthy ones via several

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routes like air, food, water, etc.

- Water borne diseases are referred to as those diseases that spreads via drinking or using contaminated water.
- Water borne diseases can also be transmitted through eating food prepared using contaminated water or using utensils which have been washed with the contaminated water.
- Entomologists collects insects for variety of reasons. The collection of insects helps to identify and research the specialty of pests.
- An aspirator is a device which is frequently used for capturing small insects like aphids, whitefly, etc.
- The beating sheet is also known as the beating net or beating tray. It is a device that is used for insect collecting.
- Vacuum device is kind of suction device that has been developed to collect insects as well as other related arthropods.
- Tullgren funnel refers to an ordinary funnel into which a handful of soil or leaf litter (generally this leaf litter is supported by a layer of mesh) is placed.
- The light trap is a great way to collect insects at night. It has three parts: a light, a funnel and a container.
- The insects, besides directly damaging the crops, sometimes become responsible for the spread of pathogens in plants.
- Plant pathogens are transmitted either via contact, or via contamination through soil or other biological agencies.
- Persistent viruses are those that persist longer within the infective agent, i.e., vector.
- In case of leafhoppers, among 110 species known to be vectors, about 100 species transmit only one virus.
- Phytoplasmas, originally known as mycoplasma-like organisms are non-culturable degenerate Gram-positive prokaryotes which are closely associated to mycoplasmas as well as spiroplasmas.
- Bacteria are microscopic organisms that can thrive well in diverse environments. Bacteria can be extremely useful for various commercial purpose as well as pathogenic too.
- Plasmids are circular double stranded DNA molecules and sometimes contains essential genes responsible for conferring antibiotic resistance to bacteria.
- Flagella are fine, thread-like, protoplasmic appendages extending via the cell wall as well as the slime layer of the flagellated bacterial cells.
- Forensic entomology refers to the scientific study of the invasion of the succession pattern of arthropods with their developmental stages of different species found on the decomposed cadavers during legal investigations.
- Flies are among the first insects that are attracted to a corpse. Their offspring, maggots, feed on moist cadavers.

- Beetles generally infest a cadaver (dead body) in the later stages of decomposition when compared to flies.
- Woodboring insects refer to a selection of arthropods which cause damage to wooden structures. This group of insects feature a range of species of insect at different stages of their life cycles from larvae to adults.
- The main beetles that cause damage to structural timber and wooden fittings, furniture and items in buildings are classified into three groups, commonly called: Deathwatch (Anobiidae family), Powderpost and False powderpost beetles (Bostrichidae family).
- Old house borers, also commonly known as house longhorn beetle,belong to a species of wood-boring beetles from the family Cerambycidae (longhorn beetles) and are characteristic due to their habit of re-infesting the same wooden material from which they have emerged.
- Prevention is the best way to control infestation by wood beetles, however, it is not always easy due to hidden feeding activities of the larvae.

1.10 KEY TERMS

- **Pathogenic insects:** Pathogenic insects are those insects that acts as an intermediate or alternative host for a pathogenic organism like bacteria, virus or fungi and transmits them to a susceptible host.
- **Vector:** A vector is referred to as an organism that acts as an intermediate or alternative host for a pathogenic organism and transmits them to a susceptible host.
- **Biological vectors:** Biological vectors are those organisms (invertebrate animals like insects) in which the disease agents or disease-causing microorganisms increase their numbers either by multiplication or transformation.
- **Biological transmission:** When the disease-agent (parasite) undergoes multiplication or some developmental changes in vector host then such transmission is known as biological transmission.
- **Propagative transmission:** When the disease-causing agent or parasite undergoes multiplication within the body of biological vector however no cyclical change is observed, then the transmission is called as propagative transmission.
- **Cyclopropagative transmission:** In cyclopropagative transmission, the parasite undergoes multiplication in the body of the vector and at the same time cyclical change is also observed.
- **Cyclodevelopmental transmission:** When the disease-causing agent like bacteria, fungi, virus or parasite undergoes no multiplication in the body of vector however they do undergo cyclical changes.
- **Non-pathogenic insects:** Non-pathogenic insects are those insects that does not act as an intermediate or alternative host for a pathogenic organism.

- **Carrier:** A carrier is referred to an organism which can spread the parasite by transmitting simply through different external body parts and which does not harbour any part of life cycle of parasite.
- **Mechanical vectors:** Mechanical vectors are those organisms where the disease-causing agent or parasites (germs) are attached to the outside of their body, like in legs and thus transmit the germs or parasites from one host to another without involving any developmental stages of the parasites in their body.
- **Aspirator:** An aspirator is a device which is frequently used for capturing small insects like aphids, whitefly, etc.
- **Pitfall traps:** A pitfall trap is a device which is used to capture pests that are active on the ground.
- **Insect vectors:** All those insects which acquire the disease causing organisms by feeding on the diseased plants, or by contact and transmit them to healthy plants are known as insect vectors of plant diseases.
- **Virions:** Viruses are inert outside a host cell, and then they are referred to as virions.
- **Plasmids:** Plasmids are circular double stranded DNA molecules and sometimes contains essential genes responsible for conferring antibiotic resistance to bacteria.
- **Flagella:** Flagella are fine, thread-like, protoplasmic appendages extending via the cell wall as well as the slime layer of the flagellated bacterial cells.
- **Pilli:** Pilli are small hair like appendages or outgrowths present on the external cell surface of bacteria.
- **Forensic entomology:** Forensic entomology refers to the branch of forensic science that deals with the study of insects for forensic analysis.

1.11 SELF-ASSESSMENT QUESTIONS AND EXERCISES

Short-Answer Questions

1. Give the general characteristics of Phylum Arthropoda.
2. What does thoracic region of insects contains?
3. Distinguish between orders Plecoptera and Phasmida.
4. Name the families that belong to order Lepidoptera.
5. Write about the modes of transmission of diseases by biological vectors.
6. Write about the life stages of *Aedes aegypti* and *Aedes albopictus*.
7. Draw the life cycle of *Phlebotomus* species.
8. What are non-pathogenic insects?
9. Define the term carrier.
10. What is the role of workers in ant family?

11. Write about some methods that can be used to control houseflies and cockroaches.
12. Why are insects collected?
13. What are aspirators?
14. What is tullgren funnel?
15. How is insect spreading done?
16. What are non-persistent viruses?
17. Name the diseases caused by fungi in plants.
18. What are woodboring beetles?

Long-Answer Questions

1. Give the classification of insects up to families. Draw a chart to show classification of insect.
2. Discuss in detail about all twenty nine orders of insects.
3. Elaborate a note on pathogenic and non-pathogenic insects.
4. Draw a well-labelled diagram to show life stages of *Aedes aegypti* and *Aedes albopictus*.
5. Discuss about water borne human diseases caused by the insects.
6. Describe about the procedure of collecting insects.
7. Discuss about preservation of insects.
8. Explain how insects acts as carrier of plant diseases.
9. Discuss the mechanism of transmission of virus into a plant.
10. Explain the role of insects in service of forensic science.
11. Discuss about the Ambrosia beetle, its life cycle and woodworm signs.
12. Describe the factors that affect the infestation by woodworm beetles.

1.12 FURTHER READING

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UNIT 2 BIOLOGICAL AND GENETIC CONTROL OF INSECT PESTS

Structure

2.0 INTRODUCTION

The principal sources of biotic stress on crops are insect pests. Hundreds of insects can cause major crop damage and are controlled by chemical pesticides, which are the primary sources of pollution and contribute to the formation and advancement of a variety of human and animal health problems. Insect pests, as well as microbiological infections and spoilage, are to blame for much of the storage loss that results in significant financial losses. These pests can be controlled using a variety of approaches including biological and genetic controls. This can be accomplished by closely monitoring the crop, only using insecticides when absolutely necessary, and cultivating pest-resistant kinds and crops. Biological methods are utilised whenever possible, encouraging the pests' natural enemies and introducing suitable predators or parasites. This unit will discuss biological and genetic control of insect pests. It will also introduce the concept of insect resistance to insecticides. In addition, it will explain principles of pesticides residues and their hazards in

India. Also, it will discuss insecticides appliances, insect migration and population fluctuation along with its factors.

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2.1 OBJECTIVES

After going through this unit, you will be able to:

- Discuss biological and genetic control of insect pests
- Understand the concepts of insect resistance, insect migration and population fluctuation
- Analyse principles of pesticides residues and their hazards in India
- Explain different types of insecticides appliances

2.2 BIOLOGICAL CONTROL OF INSECT PESTS

Biological control refers to the action of natural enemies, such as parasites, predators as well as pathogens in maintaining another organism's population density at a lower level in nature than it would occur normally in their absence. A biological method of controlling insect pest involves releasing predators/ parasites/pathogens in sufficient number in crop fields. Some of the common natural enemies are as follows:

- **Parasite:** It is an organism that derives its nutritional requirements from another organism, however, it does not kill the host immediately.
- **Predator:** It refers to the organism that kills the other organism (prey) for its nutritional requirements.
- **Ectoparasite:** It is a parasite that lives on the outside of its host, for example, larvae of parasitic Hymenoptera and Diptera.
- **Endoparasite:** It is a parasite that resides inside the body of the host to fulfil its nutritional requirements.
- **Parasitoid:** It is an insect whose larvae live, feed and develop within or on the bodies of host as parasite but eventually kills the host like a predator. Each parasitoid larva develops on a single individual and eventually kills that host. Most parasitoids are wasps, but some flies and a small number of beetles, moths, lacewings, and even one caddisfly species have evolved to be parasitoids.

When an insect lives on or inside the body of another organism, this phenomena is known as parasitism. The former is known as a parasite and the latter is known as host. There are different kinds of parasitism, which are as follows:

- **Superparasitism:** It is a type of parasitism in which the host (usually an insect larva) is attacked more than once by a single species of parasite/ parasitoid.
- **Hyperparasitism:** It is a type of parasitism in which a secondary parasite develops within a previously existing parasite or a condition in which a

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parasite lives in or upon another parasite. The parasite that attacks the host is called primary parasite and the one that attacks the primary parasite is known as the secondary parasite/hyperparasite.

- **Multiple parasitism:** It type of parasitism in which the same host has been parasitized by more than one species of parasites. Out of the two, normally only one parasite manages to develop to maturity.

2.2.1 Techniques Used in Biological Control

Biological control strategies are practiced in the following three ways:

1. **Importation and colonization of exotic natural enemies:** Generally, the dormant stage of the parasite like eggs/pupae or sometimes are shipped from the country of origin of pest. Introduction or releases of insect pest in the crop fields should be timed with the availability of the host stages to be parasitized. To evaluate the effectiveness of the introduced pathogen/parasite, samples are collected at regular intervals and analyzed as life-table data.
2. **Conservation and inundative releases of indigenous natural enemies:** Conservation of natural enemies demands judicious and minimal use of insecticides on crops, so that parasites and predators are not unnecessarily killed. Selective insecticides which are not harmful to the natural enemies are used, such as organophosphates and methyl esters. Use of favourable application technique, e.g., soil application of systemic insecticides, seed treatment and use of baits, helps to conserve the natural enemies. Sometimes natural enemies are collected from the field, mass-bred in labs and then released in the field, much like biological insecticides, e.g., use of Trichogramma and Bacillus thuringiensis.
3. **Manipulation of natural enemies:** In case of failure of natural enemy, several methods are adopted to enhance the effectiveness of natural enemies:
   - Development of more effective strains of natural enemies by artificial selection or hybridiazation under controlled conditions
   - Provision for supplementary/additional food for adults
   - Using semiochemicals, for instance, predator Chrysopa is strongly attracted to honey dew of aphids
   - Intercropping to augment parasitic activity

   Some of the examples of biological control in India are as follows:

   - In 1928, Rodolia cardinalis from the USA were released in southern India for controlling cottony cushion scale.
   - In 1941, Aphelinus mali was introduced from the USA for controlling Eriosoma lanigerum (wolly apple aphid).
   - In 1961, Prospaltella perniciosi and Aphytis diaspiditis from the USA were released for controlling San Jose scale.
   - *Trichogramma minutum, T. japonicum and T. australicum* were released in some parts of India for controlling sugarcane stemborers.
   - *Teleonemia scrupulosa* along the foothills of the Himalayas was released to control Lantana weed.

Advantages of biological control of insect pest

Some of the advantages of biological control of insect pest are as follows:

- It is a long-time, self-perpetuating as well as economical method for controlling the insect pest.
- As these predators/pathogens are present naturally in the environment, there is absolutely no fear of pest developing resistance as seen with application of insecticides.
- Use of insecticides over a long period of time causes severe soil pollution. However, there is no such fear of environmental pollution with usage of natural predator/parasite population for controlling insect pest.
- This methodology helps in maintaining the ecological balance of the nature.
- Also, with this methodology, there is no fear of pest resurgence, as typically happens with the application of insecticides.

Disadvantages of biological control of insect pest

Some of the disadvantages of biological control of insect pest are as follows:

- It is a time-consuming, long process and often takes years before these natural enemies could be well established in crop fields.
- During this period, the insect pest can cause immense damage to the main crop.
- Sometimes, these natural predator/parasite population fail to establish successfully in the crop fields leading to failure of the entire programme.
- In case of sudden pest outbreak, bio-control fails to provide immediate relief.
- In a few cases, a natural enemy can also damage some other useful animals or plants.
- It is not 100 per cent efficient and does not provide surety.
- Bio-control projects have equal chances of failure or success.

Check Your Progress

1. What do you understand by biological control?
2. Write the main difference between ectoparasite and endoparasite.
3. What was released by the USA to control Eriosoma lanigerum in the year of 1941?

2.3 GENETIC CONTROL OF INSECT PESTS

Genetic control of insect pest involves the procedure of manipulating genetic material of a pest species so as to confer lethality on the species. Inherited sterility is one of the most common approach used to control insect pest population. It involves genetic manipulation of the pest population in which such a way that the reared and released insects are fertile, however, their progenies are sterile. This effect is also known by other names such as delayed sterility, F1 sterility or partial sterility. This phenomenon is generally applied on insects belonging to the orders Lepidoptera and Hemiptera that contain polycentric chromosomes. Genetic manipulation can also be achieved by incorporating new and potentially deleterious genes (or alleles) into the genetic makeup of pest population. In effect, genetic control involves transforming a few members of a pest species into biological time bombs that eventually destroy other members of their own species. Due to the self-destructive nature of these tactics, genetic control is sometimes referred to as autocidal control.

2.3.1 Techniques Used in Genetic Control

Genetic control of the insect pest includes several techniques, which are as follows:

1. **Insect Sterilization:** The effects of irradiation on the reproductive cells of the insects cause sterilisation. The release of insects modified through transgenic (genetic engineering) procedures is not part of the process. It also avoids introducing non-native organisms into an ecosystem. As a result, when wild female insects in the pest population are inseminated by released, radiation-sterilized males, it acts as a form of 'birth control'. Insects can be sterilized by the following ways:
   - By exposing them to certain chemical agents collectively known as chemosterilants. Chemosterilants generally function by either blocking the onset of sexual maturity or by inhibiting the production of gametes eggs/sperm or by damaging the chromosomes.
   - By exposing them to non-lethal levels of ionizing radiation X-rays or gamma rays. Exposure to ionizing radiation like X-rays or gamma rays damages chromosomes either by breakage or mutation. As, cells having damaged chromosomes cannot replicate/divide properly, they normal fail to form viable gametes or produce viable offspring. Even though, the vulnerability of each insect species is different from that of other species, exposure to sufficient dose of radiation at an appropriate stage of development (generally to pupae) can often induce sterility in insects without causing other lethal side effects. These sterile individuals are reared in laboratories and released into the environment in large numbers. Once released, they can mate with 'normal' adults present in crop fields, however they fail to produce viable offspring.

   The effects of radiation on insect development was first studied in 1916, however, it was in 1930's when E. F. Knipling proposed that pest populations can be controlled by releasing large number of males in the environment that had been rendered infertile by exposure to radiation. In 1954, Knipling conducted his first mass experimentation of sterile male technique against the screwworm, *Cochliomyia hominovorax*, a Dipteran pest of livestock on the island of Curaçao. He observed that after nearly 13 weeks (four to five generations of the fly) and release of approximately a million sterile males, the screwworm population was completely eradicated from this tiny Caribbean Island. This led to mass screwworm eradication programs in the south-eastern as well as south-western United States. Further, it generated interest in eradication of

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other insect pest such as pink bollworms (*Pectinophora gossypiella*), boll weevils (*Anthonomus grandis*), tsetse flies (*Glossina* spp.) and Mediterranean fruit flies (*Ceratitis capitata*) using a sterile male technique program. However, sterile male technique projects work only in the following conditions:

- **Easy to mass-produce:** A sterile insect release program aims at rearing and releasing large number of sterile adults at a low cost.
- **Vigour of the sterile male should remain intact:** Sterile males released into the environment must be able to compete successfully for mates with normal fertile males already present in the surroundings. Further, sterile males must be physically and behaviourally identical to normal fertile males.
- **Effective for low population of insect pest:** The pest population in the crop fields must be small enough so that the initial release of sterile males will outnumber the population of normal fertile males.

2. **Conditional Lethal Mutation:** In this technique, strains of insects are produced by genetic manipulation in such a way that they carry traits that are harmful to the species in the natural environment, however, it is not detrimental under laboratory conditions. For instance, the inability to diapause (a period of suspended development in an insect or other invertebrate during unfavourable environmental conditions of temperature, humidity or absence of suitable host) would be a conditional lethal mutation in an insect that had to go into diapause to survive in the absence of host, however, no diapause would be required under laboratory conditions. A few conditional lethal traits which can be used are as follows:
    - Cold-sensitive
    - High-temperature-sensitive
    - Change in protective coloration
    - Lack of response to pheromone
    - Inability to fly
    - Lack of sex pheromone production
    - Lack of ability to develop on a particular host
3. **Cytoplasmic Incompatibility (CI)**: It refers to the phenomenon that results in the gametes, i.e., sperm and eggs being unable to form viable offspring. Sometimes, different strains of insects are not reproductively compatible, i.e., the egg cytoplasm of one strain might contain some substances that block/inhibit sperm from another strain. By mass-rearing and releasing large numbers of these incompatible insects, it might be possible to eradicate or replace a pest population with a more benign strain.
4. **Behavioural Changes:** Another technique that can be advantageous is to bring about genetic changes in the specific insect behaviours that make them undesirable or self-destructive. For instance, a change from multivoltine (producing more than one brood in a single season) to univoltine (producing

one brood in a season and especially a single brood of eggs capable of hibernating) development in many pest species, would eliminate the economic destructiveness of the pest. If researchers could recognize the genetic determinants behind such behaviour, then it would be possible to genetically manipulate the species and release the new strain in environment at such large numbers that the new released trait would become predominant in the population.

5. **Hybrid Sterility:** This technique involves producing sterile hybrids. Sterile hybrids can be raised in the laboratory and released into native populations. For instance, cross between *Heliothis virescens* males and *Heliothis subflexa* females can produce hybrid sterile (Laster et al. 1996), however, this needs to be thoroughly investigated.
6. **Simply Inherited Mutations:** This technique aims at causing genetic alteration in a single gene that can lead to decreased fitness in the wild population if somehow the gene could be introduced into the native population in large numbers. For instance, eye colour changes to increase/decrease light sensitivity, change in pupal/adult body colouration, recessive lethal mutations, deformities in structures, such as leg, wings or antennae.
7. **Double Stranded RNA Mediated Inhibition**: Double-stranded RNA (dsRNA) has been shown to induce a potent sequence-specific inhibition of gene function in diverse invertebrate and vertebrate species. This approach has been tested in the fruit fly (*Drosophila melanogaster)* (Kennerdell and Carthew, 1998; Kennerdell and Carthew, 2000), who proposed that delivery of dsRNA involved generating transgenic insects that express double stranded RNA molecules or injecting dsRNA solutions into the insect body or within the egg sac prior to or during embryonic development. A reduction in pest infestation is obtained via suppression of gene expression.
8. **Reciprocal Translocations:** It refers to the mutual exchange of fragments between two non-homologous chromosomes (broken chromosomes), one part of one uniting with part of the other, i.e., the broken piece sometimes attaches itself to another chromosome. Reciprocal translocation can occur naturally or it can be induced by exposure to radiation. If the disruption occurs without damaging the vital portion of the genome, the organism appears normal and also carries the entire genetic information. However, the genetic alteration manifests during the production of gametes in metaphase I, where homologous parts of the original chromosomes fail to line up with one another due to reciprocal translocation. This phenomenon can also be used to genetically control insect pest population.

Check Your Progress

4. Write the other names of genetic control.
5. On which orders does the phenomenon of genetic control apply?
6. Which phenomenon produces sperms and eggs?

2.4 INSECTS RESISTANCE TO INSECTICIDES

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The term 'insect resistance' refers to an insect's ability to endure the poisonous effects of an insecticide to the point where it can no longer be controlled with that chemical. Insecticides belong to different classes, namely organophosphates, carbamates, pyrethroids, neonicotinoids, etc. All of them share a similar chemical structure as well as mode of action. The primary role of an insecticide is to kill an insect via a specific mode of action, or somehow inhibits the growth of insects. A target site of action denotes the specific area where the inhibitor interferes with an enzyme's activity within a metabolic pathway of an insect or a pest. Numerous factors are responsible or contribute to the development of insecticide resistance in both insects as well as pests, including genetics as well intensive insecticide application. Consequently, insects with genes conferring resistance to a certain insecticide or group of insecticides survive their treatment and become selected to continue passing this resistance on to subsequent generations. Apart from the various kinds of pests, insects are known for exhibiting alarming rates of resistance to insecticides. Around 500 species of insects as well as associated arthropods are resistant to insecticides throughout the world. Generally, insects exhibit resistance to a variety of insecticides with the same mode of action. For instance, one of the classic example of insecticide resistance has been observed in housefly (*Musca domestica*). The population of housefly that became resistant to Dichlorodiphenyltrichloroethane (DDT) in the 1950s were also resistant to pyrethroid insecticides decades later, with no previous exposure. The mode of action of DDT as well as pyrethroid insecticides is identical. This phenomenon is referred to as cross resistance. Further, multiple insecticide resistance happens whenever a population of insects resists two or more insecticide classes having different Modes Of Action (MOA).

Multiple resistance mechanisms are expressed by insects that develop this type of resistance. This process takes place when initially insects are exposed to one insecticide and they develop resistance to this particular insecticide. The exposure to first insecticide is followed by halting the use of that insecticide and a new insecticide is used instead. Now, insects develop resistance to the second insecticide also. This cycle of resistance keeps on continuing. For instance, the Colorado potato beetle is notorious for resisting more than 50 insecticides with different modes of action.

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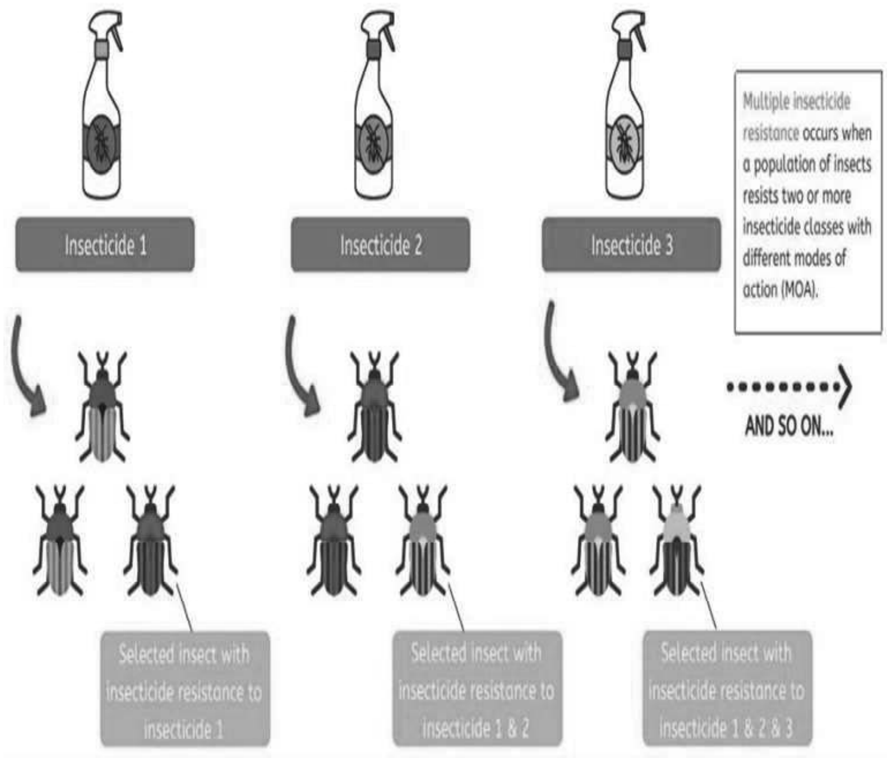

Fig. 2.1 *Multiple Insecticide Resistance in Insects*

Even though, the mechanism of multiple resistance is less usual as compared to cross resistance, it bears huge consequences as it significantly decreases the number of insecticides that can be used to control the population of a specific insect. Further, insecticide resistance and insecticide tolerance are two different phenomena. Insecticide tolerance is a natural tendency/phenomenon, and it is not a result of selection pressure. Insecticide tolerance is not developed by exposure to the insecticide, rather it occurs naturally. On the contrary, insecticide resistance is a result of selection pressure. For instance, due to differences in body size, exoskeleton thickness, as well as ability to metabolize poisons, mature caterpillars are more tolerant towards insecticides as compared to younger ones belonging to the same species. Hence, rather than considering this as true insecticide resistance, these differences are considered to be tolerance or natural resistance.

Insecticide resistance has evolved in multiple insect species over a period of time. In 1914, resistance to insecticides for the first time was documented by A. L. Melander when scale insects demonstrated resistance to an inorganic insecticide. Further, between the year 1914 to 1946, 11 additional cases were reported and recorded. The development of organic insecticides, like DDT, gave hope that insecticide resistance was a dead issue. However, by the year 1947, development of resistance to insecticide in housefly (*Musca domestica*) had evolved. With the introduction of every new insecticide class cyclodienes, carbamates, formamidines, organophosphates, pyrethroids, even *Bacillus thuringiensis* – cases of resistance surfaced within two to 20 years.

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Some of the common examples of insecticide resistance are as follows:

- Research conducted in America has shown that fruit flies that infest orange groves were becoming highly resistant to Malathion.
- In Hawaii, Japan as well as Tennessee, the diamondback moth evolved a resistance to *Bacillus thuringiensis* about three years after the farmers began to use it heavily.
- DDT is no longer effective in preventing malaria in some places.
- In the southern United States, *Amaranthus palmeri*, which interferes with the production of cotton, has become highly resistant to the herbicide glyphosate and in general it has developed resistance to five sites of action in the southern US by the year 2021.
- The Colorado potato beetle has evolved resistance to approximately fifty two different compounds belonging to almost all major insecticide classes. Even though, the resistance levels change across the populations and between beetle life stages, yet in few situations it can be very high (up to 2,000-fold).
- The cabbage looper is an agricultural pest that is becoming increasingly problematic due to its increasing resistance to *Bacillus thuringiensis,* as demonstrated in Canadian greenhouses.

2.4.1 Factors Responsible for Development of Insecticide Resistance

Insecticide resistance probably stems from the following multiple factors:

- Several pest species produce large numbers of offspring, for instance, insect pests produce large broods. This leads to increases in the probability of mutations and further safeguards the rapid expansion of the resistant populations.
- Pest species had been exposed to natural toxins even before the beginning of agricultural practices. For instance, several plants produce phytotoxins in order to protect them from herbivores. Consequently, coevolution of herbivores and their host plants required development of the physiological capability to detoxify or tolerate poisons.
- Human beings usually depend majorly on insecticide for controlling the insect population. This increases selection pressure towards the development of resistance. Insecticides that fail to break down rapidly often contribute to selection for resistant strains even after they are no longer being applied.
- In response to resistance towards insecticides, the user may increase either the quantity or the frequency of the insecticide applied, which worsens the problem. Additionally, few insecticide/pesticides are toxic toward species that feed on or compete with the pest population. This can unexpectedly allow the pest population to increase, requiring more of the pesticides. This phenomenon is known as the pesticide trap or a pesticide treadmill, as the user increasingly pay more for less benefit.

- Insect predators as well as parasites usually have smaller populations and are less likely to evolve resistance as compared to the primary target of pesticide like mosquitoes as well as those that feed on plants. Weakening them allows the pests to grow. Otherwise, resistant predators can be bred in laboratories.
- Pests having limited viable range (like insects feeding on a specific diet of a few related crop plants) are more likely to evolve resistance, as they are exposed to higher pesticide concentrations and has less opportunity to breed with unexposed populations.
- Pests having shorter generation times develop resistance more quickly as compared to others.
- Users generally farmers following the common practices of their peers is occasionally problematic as over relying on pesticides is the most common mistake and becomes increasingly popular as farmers conform to the practices around them.
- Unusualness with difference in regulatory enforcement can further hinder the ability of the policy makers to produce real change in the course of resistance evolution.

2.4.2 Mechanism of Insecticide Resistance

Insect populations can develop resistance to insecticides in several ways and pest population may or may not employ more than one mechanism simultaneously. Resistant insects may be able to detoxify or destroy the poison more quickly than susceptible insects, or they may be able to rid their bodies of the dangerous compounds more quickly.A representation of mechanism of insecticide resistance is shown in Figure 2.2.

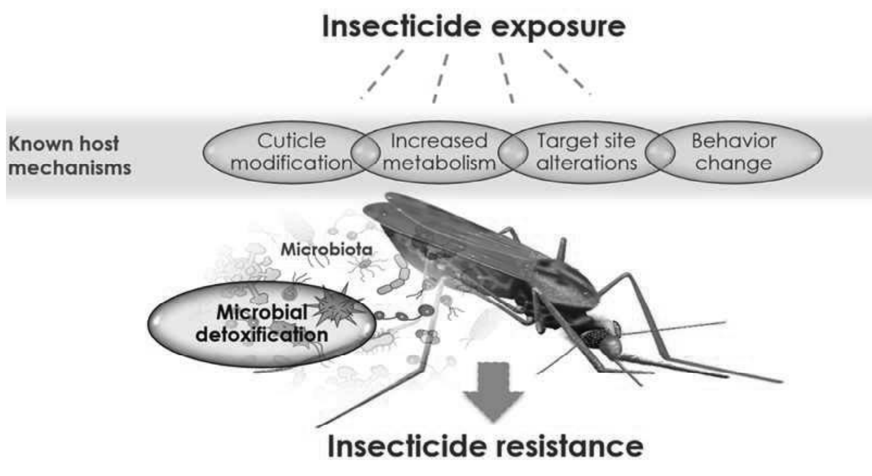

Fig. 2.2 *Insecticide Resistance*

The different types of resistance are as follows:

1. **Metabolic resistance**: Insect exhibiting resistance to toxin or insecticides are able to detoxify or destroy the insecticide/toxin quickly when compared to an insect which is vulnerable to a specific toxin/insecticide. Insect resistant to insecticide can also bind the toxin/insecticide to proteins present in their

bodies in order to prevent it from reaching the target site. A common mechanism of resistance is referred to as metabolic resistance, which can pose the most difficult challenges. Insects showing resistance to insecticides may develop higher levels or more potent forms of the enzyme(s) that break down insecticides into nontoxic by-products. Metabolic resistance is one of the most common mechanism and often presents the greatest challenge. Insects use their internal enzyme systems to break down insecticides. Resistant strains may possess higher levels or more efficient forms of these enzymes. In addition to being more efficient, these enzyme systems also may have a broad spectrum of activity (i.e., they can degrade many different insecticides).

2. **Altered target-site resistance**: In the altered target-site resistance mechanism, insect showing resistance to insecticide alter the target site where the toxins from the insecticide bind to their body. By this way the effect of insecticide is reduced or even nullified. The target site where the insecticide acts in the insect may be genetically modified to prevent the insecticide binding or interacting at its site of action thereby reducing or eliminating the pesticidal effect of the insecticide.

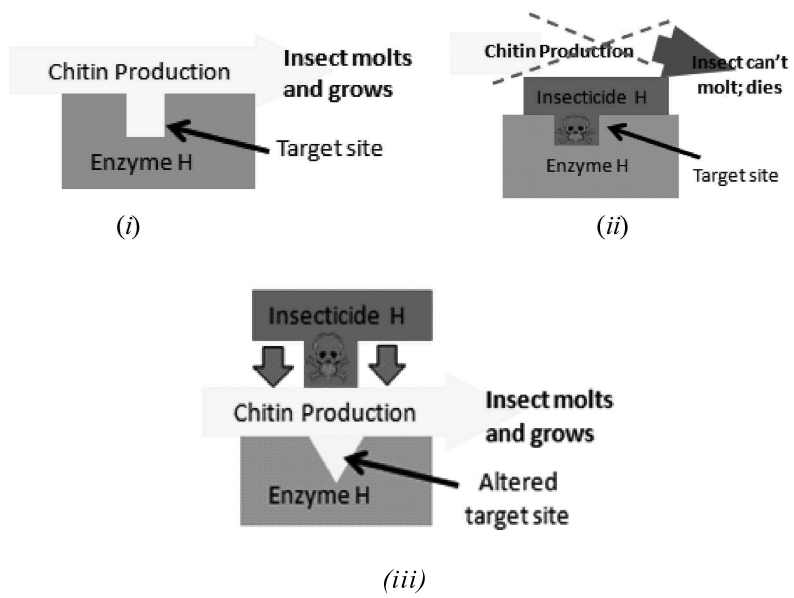

***Fig. 2.3** Mechanism of Altered Target Site Resistance in Insects*

3. **Behavioural resistance**: In the behavioural resistance mechanism, the insects modify their behaviours like traditional movement behaviour as well as feeding behaviour. For example, if the leaf on which insect is feeding is sprayed with insecticide, the insects may stop feeding on that particular leaf or may move to begin feeding on the underside of the leaf. Thus, resistant insects may avoid the toxin by a change from their normal activity. For example, in Africa, malaria-transmitting mosquitoes evolved to rest outside, which prevented them from coming in contact with pesticides sprayed on interior walls.

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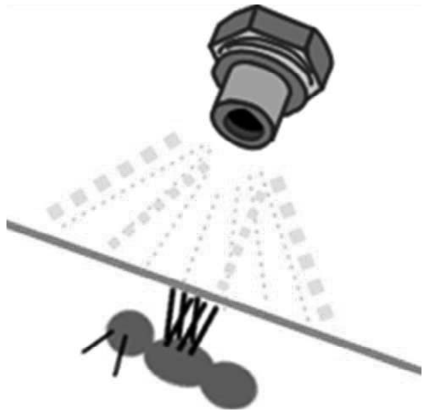

Fig. 2.4 Behavioural Resistance in Insects

4. **Penetration resistance:** In the penetration resistance, the outer cuticle of an insect can develop barriers which can slow down the chemical absorption into its body, which is known as penetration resistance. Insects which are resistant to insecticide may absorb the toxin less gradually when compared to vulnerable insects. This mechanism is frequently used in conjunction with other mechanisms.

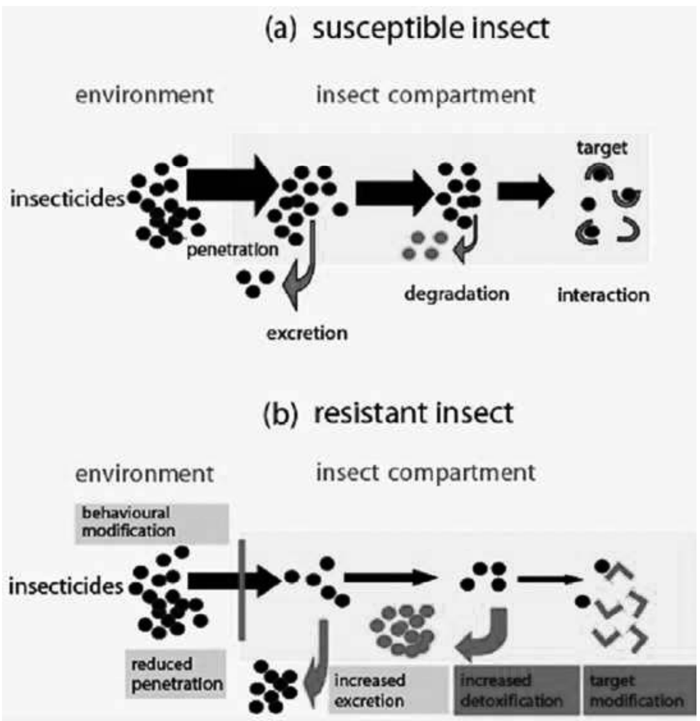

Fig. 2.5 *Scheme of Potential Behavioural and Physiological Changes Associated with Insecticide Resistance in Malaria Vectors; (A) Susceptible Insect; (B) Resistant Insect*

2.4.3 Reasons of Failure of Insect Control Measures

However, insecticide resistance is not the sole reason behind failure of insect control. Before arriving at a conclusion related to insecticide resistance, the following measures should be covered to differentiate between poor pest control as well as

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insecticide resistance of insects:

- There might be an error in the identification of pest and accordingly incorrect insecticide/pesticide may be used to control it.
- Inappropriate dosage of insecticide/Pesticide is used to control pest population.
- Timing of application of insecticide/pesticide is not appropriate. For instance, insecticide/pesticide was applied before the arrival of the pest or sometimes pesticide was applied at a certain life stage of the insect when it is not vulnerable to the application of insecticide/pesticide.
- The area is reinfested with pests after the successful application of insecticide/ pesticide
- The natural enemy of the pest (predator) as well as the pest (prey) itself got irradiated by the application of the insecticide/pesticide. As the population of the pest is recovering again, the population of the natural enemy of the pest takes time to reach an effective level. Therefore, due to a lack of number of predators (natural enemy of the pest), the population of the prey (the pest) increases.
- A few non-targeted pests, which usually do not occur at substantial levels, can reach damaging levels after the application of insecticide/pesticide. This is due to the elimination of natural enemies by the application of pesticide/ insecticide. In insecticide/pesticide-treated areas, the secondary pest population can regain control rapidly as soon as the natural enemies are reduced.

2.4.4 Steps to Prevent Insecticide Resistance

Insecticide resistance can be prevented via adopting Integrated Pest Management (IPM) techniques as well as pesticide management in the following ways:

1. **Identifying and monitoring the pest population**: Using research-based sampling techniques in order to determine whether pesticides are required and if necessary, looking for the best time for applying insecticide/pesticide.
2. **Practicing suitable control measures**: Insect pests can be controlled by adopting different methods like natural or cultural methods of pest control, physical or mechanical methods of pest control, pheromone traps, biological methods of pest control, chemical or modern methods of pest control, genetic method of pest control and Integrated Pest Management or IPM measures of pest control. Integrated Pest Management (IPM) refers to the collective methods used for controlling pest. It employs all appropriate methods of pest control to decrease pest populations and maintain them below economic injury level.
3. **Using tank-mix:** This methodology involves mixing two or more than two insecticide/pesticide having different modes of action in a tank-mix or pre-pack, the onset of existing pest resistance may be delayed or mitigated. The ratio of pesticides can be adjusted based on local pests and environmental conditions with tank-mixing.

4. **Using globally standardized codes for selecting as well as spraying of insecticide/pesticide:** Insecticide Resistance Action Committee (IRAC) is an industry-organized group of pest management experts who develop international guidelines on pest resistance management. A classification scheme which is based on group numbers was developed by the Insecticide Resistance Action Committee (IRAC) to make it easy to differentiate between different classes or mode of action (MOA). The US Environmental Protection Agency has instructed agricultural chemical companies to prominently print the IRAC MOA group number on insecticide labels in a standard format For instance, the mode of action of insecticides belonging to the same group number is the same. A premix label that indicates the group number/numbers makes it easy for a user to identify the modes of action included in the premix.
5. **Careful selection of insecticide:** Some of the instructions must be kept in mind while selecting insecticides for pests, which are as follows:
    - Instructions mentioned on the insecticide/pesticide containers related to dosage and methodology to be adopted must be properly followed for best results.
    - In scenario, where, multiple application of pesticide is inevitable, use insecticides having differing mode of action. This will prevent the repeated use of insecticides having the same mode of action leading to development of insecticide resistance.
    - Avoid using long residual insecticides.
    - For some specific kinds of cropping systems, depending on the stage of crop development as well as the biology of the target pest, insecticide applications are usually arranged/divided into MOA spray blocks or windows. Make sure to follow these time windows and then apply the insecticide/pesticide at the appropriate time.
    - Option of 'spot treatment' must be kept open, whenever possible. For instance, hot spots in the field infested with insects or edges of the field.
    - In order to plan for future years, it is also advisable to keep a good record of insecticides used.

However, in case, all the methods as well as steps mentioned above are adopted and yet there seems to be a problem of pests as well as insects in the field, then probably insects have developed high resistance to insecticides. Following remedies can be practiced to fight insecticide resistance:

- Stop using that particular pesticide/insecticide as well as any other insecticides that is having the same mode of action.
- Use an insecticide/pesticide having different mode of actions.
- Take suggestion from the local farmers or fertilizer/pesticide suppliers. They will be able to advise better based on their previous experiences.
- Get in touch with the local, state or central agricultural authority or insect management services. For instance, In India, such authority is Central Insecticides Board.

- Further, for assistance with long-term planning of insect control in subsequent crops, one can always visit the Insecticide Resistance Action Committee website at: http://www.irac-online.org/.

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Check Your Progress

7. Give one classic example of insecticide resistance.
8. Write the different types of resistance an insect can develop to insecticides.
9. What are the objectives of IPM?

2.5 PRINCIPLES OF PESTICIDES RESIDUES AND THEIR HAZARDS IN INDIA

A pesticide refers to a substance or to a mixture of substances which are used for killing pests, i.e., organisms capable of destroying cultivated plants or animals. The term pesticide is a general term which applies to numerous chemicals like insecticide, fungicide, herbicide as well as nematocide. Applications of pesticides to crops or animals may leave residues either in or on food when it is consumed, and those specified derivatives are considered to be of toxicological significance. Pesticide residues refer to the pesticides that may remain on or in food after they are applied to food crops. The ultimate levels of these pesticide residues in foods are usually specified by regulatory bodies in several countries. Exposure of the general population to these residues most commonly occurs via consumption of treated food sources, or being in close contact to areas treated with pesticides like farms or lawns surrounding the houses.

A lot of chemical residues, particularly derivatives of chlorinated pesticides, show bioaccumulation. Bioaccumulation refers to the entry of a pollutant or toxic/hazardous substance in the food chain while biomagnification is defined as the increase in concentration of a toxic substance at each successive trophic level after entering into food chain. In bioaccumulation, the concentration of the toxic substance increases in the organism of same type as the toxic substance is retained in the body of the organism while in biomagnification, the toxic substance gets accumulated in the body of organisms at successive trophic levels at a higher concentration than the previous trophic level. For instance, the classic case of DDT pesticides. It is a non-biodegradable chemical. When DDT enters aquatic bodies (for example, lakes, streams and rivers), it gets incorporated in the food chain and build up in the body of fishes. This step is known as bioaccumulation. As the fish eaten up by animals of higher trophic levels, concentration of DDT keeps on increasing at each successive trophic level and this is referred to as biomagnification. Persistent chemicals can be magnified through the food chain, and have been detected in products ranging from meat, poultry, and fish, to vegetable oils, nuts, and various fruits and vegetables.

2.5.1 Classification of Pesticides

Pesticides can be classified in the following ways:

I. According to Pest they Control

- **Herbicides**: They refer to the pesticides which are used for killing weeds or herbs. For example, Gramoxone.
- **Insecticides:** They refer to the pesticides which are used for killing insects. For example, Sevin.
- **Fungicides:** They refer to the pesticides which are used for killing fungi. For example, ManKocide.
- **Nematicides:** They refer to the pesticides which are used for killing nematode. For example, Furadan.
- **Rodenticides:** They refer to the pesticides which are used for killing rodents (rat and mice). For example, Klerat.
- **Acaricides:** They refer to the pesticides which are used for killing aracnids (mites). For example, new Mectin.
- **Molluscocides**: They refer to the pesticides which are used for killing molluscs (snails and slugs). For example, Slugit.

II. According to Mode of Action

1. For Insecticides

- **Contact**: These pesticides are used to kill only insects they are sprayed or dusted onto.
- **Stomach acting**: These pesticides are used to kill only insects that eat plant parts sprayed with insecticides. For example, Dipel.
- **Systemic:** These pesticides are transported within the plant and kill insects when they suck sap or eat parts of the plant.
- **Fumigant:** These pesticides are used to kill insects that inhale toxic vapours of the chemical. For example, Phostoxin.

2. For Fungicides

- **Contact (Protectant):** These pesticides are used to kill only fungi sprayed or dusted with the fungicide, or fungal spores, which come into contact with the fungicide. For example, Kocide
- **Systemic (Eradicant):** This type of fungicides is transported only within the plant and then kills fungi growing up within tissue of the plant.

3. For Herbicides

- **Pre-emergence:** It refers to a type of herbicide which has been applied to the soil during the period after planting as well as before germination (which generally happens after 1-5 days of land preparation). For example, Gesaprim.
- **Selective:** It refers to a type of herbicide which kills small weeds as well as seeds however leave the crop unharmed. For example, Gesagard.

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- **Post-emergence:** It refers to a type of a herbicide which is applied to growing weeds after crop emergence or transplanting. For example, Fusilade and Gramoxone.
- **Contact:** It refers to a type of a herbicide which kills only soft green parts of weeds sprayed with the herbicide. For example, Gramoxone.
- **Systemic:** It refers to a type of herbicide which is absorbed into the plant after spraying, and is transported to other plant parts where it causes death.
- **Non-selective:** It refers to a type of herbicide which kills all plants sprayed upon.

III. According to Formulation

- **Dust:** These pesticides are prepared as dry fine particles. For example, Sevin
- **Granules (G):** These pesticides are prepared as large dry particles. For example, Furadan.
- **Wettable powders (WP):** These pesticides consist of finely divided
- particles with other substances which enable the powder to be mixed with water to form a stable suspension. For example, kocide.
- **Emulsifiable concentrate (EC):** These pesticides are dissolved in an organic solvent to which an emulsifier is added to enable proper mixing.
- **Dry bait:** These pesticide are mixed with edible products to form dry pellets, which are attractive to pests. For example, Klerat.
- **Smokes:** These pesticides are mixed with an oxidant and combustible material, which generates hot gas. For example, mosquito coil.

IV. According to Active Compound (Active Ingredient)

- **Chlorinated hydrocarbon**: Chlorinated hydrocarbon refers to a hydrocarbon containing chlorine, like insecticide DDT (dichlorodiphenyltrichloroethane). These compounds continue in the environment and can accumulate in several animals as well as in food chains. For example, Kelthane.
- **Organophosphates:** Organophosphates refers to a class of organophosphorus compounds having the general structure O=P (OR)3, a central phosphate molecule with an alkyl or aromatic substituents. Organophosphates can be regarded as esters of phosphoric acid. The organophosphates are now the largest as well as the most useful class of insecticides. Two broadly used compounds in this class are parathion as well as Malathion; others include Diazinon, naled, methyl parathion, as well as dichlorvos. They are particularly operative against sucking insects like aphids and mites, which love to feed on plant juices. The chemicals' absorption into the plant is achieved either via spraying the leaves or by applying solutions saturated with the chemicals to the soil, so that intake occurs via the roots. The organophosphates generally have little residual action and are essential, hence, where residual tolerances limit the choice of

insecticides. They are usually much more toxic when compared to the chlorinated hydrocarbons. Organophosphates kill insects generally by inhibiting the enzyme cholinesterase, which is essential in the functioning of the nervous system. For example, Basudin.

- **Carbamate:** The carbamates refers to a group of insecticides comprising of compounds like carbamyl, methomyl, as well as carbofuran. They are quickly detoxified and eliminated from animal tissues. Their toxicity is thought to arise from a mechanism which appears to be rather comparable to that for the organophosphates. For example, Sevin.
- **Pyrethroids:** Generally, the common names for Pyrethroid end in either -*thrin* or -*ate*. For example, allethrin, resmethrin, permethrin, cyfluthrin or esfenvalerate are pyrethroids. Pyrethroid insecticides refer to a special chemical class of active ingredients which are seen in several of the modern insecticides found on store shelves as well as used by pest management professionals. The name pyrethroid refers to 'pyrethrum-like' and refers to the origin of this class of pesticides.

  All the pesticides belonging to Pyrethroids are equally toxic as well as effective against the same pests. Nevertheless, most pyrethroid insecticides share the following characteristics:

  - They are low in toxicity to mammals as well as birds.
  - They are high in toxicity to fish if they are applied directly to water.
  - They need very low doses to kill insects (they exhibit very high arthropod toxicity).
  - They act rapidly.
  - They are particularly effective against chewing insects, even though several pyrethroid insecticides can be absorbed by the insect pest when it just walks over the dry residue.
  - They bind firmly to soil as well as other organic matter (hence they are not as effective in penetrating soil to kill underground pests).
  - They do not dissolve easily in water.

  They are one of the most popular insecticide used in the year 1990s as replacements for older pesticides, like diazinon and Dursban that were phased out for the good of environment as well as human health. A few pyrethroid insecticides remain for longer duration in the environment for days or weeks altogether, particularly, when protected from sunlight. Other pyrethroids, like allethrin as well as resmethrin, break down within a few minutes to a few hours after application, for example, Decis.

V. According to Persistency

- **Persistent:** This class of pesticide remains in the environment for a longer duration of time. For example, Hyvar-x.
- **Non-persistent:** This class of pesticide remains in the environment for a very short duration of time. For example, Dipel.

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2.5.2 Regulations or Policies

Each country adopts their own agricultural policies as well as Maximum Residue Limits (MRL) and Acceptable Daily Intake (ADI). The level of food additive usage varies by country because forms of agriculture are different in regions on the basis of their geographical or climatical factors. Pre-harvest intervals are also set to require a crop or livestock product not be harvested before a specific period after the application of pesticides in order to allow the pesticide residues to decrease below the maximum residue limits or other tolerance levels. Similarly, restricted entry intervals are the amount of time to allow residue concentrations to decrease before a worker can re-enter an area where pesticides have been applied without protective equipment.

Crop protection chemicals, i.e., pesticides are an essential constituent of agriculture as they play a major role in protecting the crop as well as other produce from pests and hence increase the productivity of the farm. However, the non-judicious use of pesticides has resulted in unwanted pesticide residues in food, feed, soil as well as water. Pesticides in India are registered under the Insecticide Act, 1968, and pesticide residue in food commodities are regulated through the Food Safety and Standards Act, 2006. Due to variations in agricultural practices followed across the nation, analysis and work plans, the pesticide residue data usually is not consistent and hence arises the urgency to normalize the work going on pesticide residues across the entire nation. Accordingly, the Indian Council of Agricultural Research (ICAR) initiated All India Coordinated Research Project (AICRP) on Pesticide Residues in 1984-85. This was later re-designated as the All India Network Project on Pesticide Residues (AINP-PR). The Project Coordinating Cell is located at ICAR-Indian Agricultural Research Institute, New Delhi and presently there are 19 coordinated centres, out of which 14 of the are accredited by the National Accreditation Board for Testing and Calibration of Laboratories (NABL) in the field of chemical testing as per ISO/IEC 17025. The mandate of the project is to organize, promote, coordinate as well as to conduct location-specific research at national levels on analysis of pesticide residues in food commodities, soil as well as in water for ensuring food safety and security.The project has been generating persistence/residue data of pesticides on crops in different agro-climates for fixing the Pre-Harvest Interval (PHI), approval of label claim and fixation of maximum residue limits (MRLs) for the safety of consumers.

The residue data is submitted to Food Safety and Standards Authority of India (FSSAI) for dietary risk assessment as per OECD Guidelines and fixation of national MRLs to protect the health of the consumers. This data is also shared with Food and Agriculture Organization (FAO)/ World Health Organization (WHO)/ Codex Committee on Pesticide Residues (CCPR) for setting Codex MRLs (CXLs) at international level to ensure fair international trade. AINP-PR is actively engaged in developing policy guidance documents as well as discussion papers on certified reference materials, low public health pesticides, unsupported pesticides, methods of analysis at the international level; and for field persistence, crop grouping etc. at national level. In the year 2007, AINP-PR brought out a very popular first edition of the Pesticide Residue Analysis Manual. This edition got huge success and is followed by a revised edition in the year 2013. In the Public-Private Pseartnership

(PPP) mode, AINP-PR takes up the industry sponsored trials for generation of pesticide residue data on existing and new molecules/formulations. As a part of human resource as well as skill development initiative, AINP-PR carries on refresher training programmes on pesticide residue analysis for project scientists as well as other researchers from across the country. A lot of general awareness is created about the safe use of pesticides among the farmers as well as the general public via participation in Krishi Vigyan Kendras (KVKs), Krishi Vigyan Melas, Mera Gaon Mera Gaurav (MGMG) and the media.

Objectives of the All India Network Project on Pesticide Residues

The objectives of the All India Network Project on pesticide residues are as follows:

- It aims to study the persistence/dissipation of pesticides in crops via multi-location supervised field trials in different agro climates following Good Agricultural Practices (GAP) to work out the safe waiting period, approval of label claim and fixation of Maximum Residue Limit (MRL).
- It also aims to monitor different agricultural produces/commodities as well as environmental samples like soil, water for possible presence of pesticide residues.
- It aims to develop as well as validate simple, sensitive and cost-effective analytical methodology for quantification of pesticide residues in different components of the environment.
- It also aims to study the decontamination of pesticides in different food commodities.
- It aims to maintain up-to-date information regarding pesticide residues as well as to provide guidelines to research and extension workers in the country.
- It aims to create awareness as well as to educate and train the farmers, extension workers and other stakeholders on safe and judicious use of pesticides.
- It aims to maintain the quality of data generated by maintaining continuous NABL accreditation as per ISO/IEC 17025.

Monitoring of Pesticide Residues at National Level (MPRNL)

The MPRNL scheme was initiated by the Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare as a central sector scheme during the year 2005-06 in order to frequently monitor pesticide residues in food commodities as well as other environmental samples like soil and water. The research laboratories participating in the scheme across the country represents the Ministry of Agriculture and Farmer's Welfare, Ministry of Health and Family Welfare, Ministry of Environment and Forest, Ministry of Chemical and Fertilizer, Ministry of Commerce, Indian Council of Agriculture Research, Council of Scientific and Industrial Research and State Agricultural Universities. The primary objectives of the scheme are as follows

- One of the objective of the scheme is to identify crops as well as regions having majority of pesticide residues in order to focus extension efforts for Integrated Pest Management (IPM) and Good Agriculture Practices (GAP).

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- Another major objective of the scheme is to test pesticide residues as well as other contaminants present in food commodities and environmental samples like soil and water.
- The scheme also aims at strengthening the infrastructure at Quarantine stations so as to prevent entry of food and food commodities which have pesticide residues above maximum residue limit (MRL).
- The scheme also aims at testing/certification of pesticide residue in export/ import samples.

The execution of the scheme, i.e., the MPRNL scheme is observed/ supervised by two committees, namely Steering Committee and Technical Committee. The policy decisions are connected to the scheme are under the preview of the Steering Committee which is headed by the Joint Secretary (Plant Protection), Department of Agriculture, Cooperation and Farmers Welfare and the Technical Committee, headed by the Assistant Director General (Plant Protection), Indian Council of Agriculture Research (ICAR) related to the technical issues. The Project Coordinating Cell of AINP on Pesticide Residues is the nodal center for implementation of the scheme. The Network Coordinator, All India Network Project on Pesticide Residues, ICAR-IARI, New Delhi is the Member Secretary of the scheme and is the nodal person for the day-to-day execution of the scheme concerned with financial or technical matters and submission of reports on monthly basis, annual basis or on the basis of requirement to the Department of Agriculture, Cooperation and Farmers Welfare. The participating laboratories gather food commodities like vegetable, fruits, cereals, pulses, spices, curry leaves, red chilli powder, milk, egg, fish/ marine, meat, tea as well as oilseeds according to the approved technical programme during the annual workshop of the scheme and then analyse for the likely presence of pesticide residues. The food commodities samples are collected from several retail outlets, local markets/ vendors, Agriculture Produce Marketing Committee (APMC) markets, farmer's field, local farmer's markets, CIPMC, organic outlets and Public Distribution Systems (PDS) and surface water from intensive agricultural fields from different parts of the country.

For ensuring the consistency in the adopted methodology like sampling, extraction as well as clean-up of the samples, the 'Pesticide Residue Analysis Manual' reviewed and published by the Indian Council of Agricultural Research, has been provided and followed by all the participating laboratories. Additionally, on the basis of requirement, new analytical methods are developed, validated and adopted by the laboratories.

Under the central sector scheme of 'Monitoring of Pesticide Residues at National Level' sponsored by Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture & Farmers Welfare, 33 participating laboratories gather the samples of vegetable, fruits, spices, curry leaves, red chilli powder, rice, wheat, pulses, milk, fish/marine, tea, meat, egg, oilseeds as well as water from retail outlets, APMC markets, mother dairy, organic outlets, farm gate and farmgate samples provided by CIPMC located in various parts of India and analyze these samples for the likely presence of different groups of pesticides like organo-chlorine, organo-phosphorus, synthetic pyrethroids, carbamates, neonicotinoids, herbicides, fungicides, etc. The research laboratories involved in the participation of samples comes under the monitoring scheme are continuing accreditation by National Accreditation Board for Testing and Calibration of Laboratories (NABL) in the field of pesticide residue analysis as per ISO/IEC 17025. Under the scheme, the samples of commodities vegetables, fruits, spices, red chilli powder, curry leaves, rice, wheat, pulses, fish/marine, meat and egg, tea and milk were gathered from the retail outlets, mother dairy as well as Agricultural Produce Marketing Committee (APMC) markets, farm gate, organic outlets and surface water from water resources like ponds, reservoirs, lakes, river, etc., located at several parts of the country and analysed by 30 NABL accredited participating laboratories for the possible presence of pesticide residues. During 2008 to 2019, a total of 2,11,188 samples of different food commodities have been collected and analysed for the presence of pesticide residues and the residues were found exceeding above Food Safety and Standard Authority of India (FSSAI) Maximum residue Limit (MRL) in 4,495 (2.1%) samples.

2.5.3 Decontamination of Pesticide Residues in Food Commodities

Pesticide residues are detected in vegetables, fruits, pulses, cereals as well as other food commodities after their pre-harvest or post-harvest application. The deposition of pesticides in different food parts differs with the type and chemical structure of the pesticide applied, type of food material on which the pesticide has been applied as well as other environmental conditions. Hence, decontamination of pesticide residues from food commodities remains the primary area of concern for consumers specifically when these commodities are consumed raw. Numerous decontamination methodologies are being assessed for actual removal of pesticide residues from several vegetable like okra, chilli, cabbage, cauliflower, tomato as well as brinjal.

2.5.4 Hazards of Pesticide Residue on Health

Pesticides are toxic and exposure to pesticides can lead several health issues. They are associated with serious illnesses and are capable of causing diseases ranging from respiratory problems to cancer. The different health impacts of pesticide residue are as follows:

- Pesticides can be highly toxic or poisonous. They can have severe effects of can be lethal too even after a single episode of ingestion, inhalation or skin contact. The symptoms manifest soon after exposure or can arise within 48 hours. They can cause the following problems:
  - Irritation or infection of the respiratory tract
  - Sore throat and/or cough
  - Allergic sensitisation
  - Eye as well as the skin irritation
  - Nausea
  - Vomiting
  - Diarrhoea

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- Headache
- Loss of consciousness
- Extreme weakness
- seizures and/or in extreme cases can lead to death

- However, pesticides generally cause harmful effects after being exposed for a very long period of time even if the exposure is minimal. Low doses don't necessarily cause immediate health effects, however, when the body is exposed to pesticides for a very long duration of time, they can cause very serious illnesses.
- Long-term exposure to pesticide has been associated with the development of certain diseases like Parkinson's disease, asthma, depression or anxiety, Attention Deficit and Hyperactivity Disorder (ADHD), and cancer, including leukaemia and non-Hodgkin's lymphoma.
- Exposure to pesticide is also capable of disrupting the balance of endocrine system. Endocrine system of the body is responsible for releasing hormones. Hormones are the chemical messengers of the body, which helps to regulate and coordinate body functions internally as well as play essential role in growth, development and reproductive function of an organism. Exposure to pesticide can disrupt the endocrine function in the following ways:
  - It can reduce the quality as well quantity of semen which is followed by decreased fertility, genital malformations, testicular as well as development of prostate cancer.
  - It can lead to early puberty, appearance of cysts in the ovaries (a condition known Polycystic Ovary Syndrome (PCOS), uterus anomalies, breast cancer, pregnancy problems with early abortions, decreased fertility, etc.
  - It can cause diabetes and obesity.
  - It can cause serious neurological disorders, particularly disorders in brain development.
  - It can also cause hyper and hypo thyroidism and thyroid tumours.
- A substance is regarded as carcinogenic only when there is indication that it can cause cancer. There are many numerous types of cancer, however, all of them can be specified by the development of abnormal cells that start to divide without control and spread into the surrounding tissues. Single exposure to pesticides hardly causes cancer, however, repeated exposure even in small quantities via skin, eyes or simply ingestion can cause cancer.
- The major concerning issue regarding exposure to pesticides is the fact that the effects of individual chemicals can be enhanced or altered when combined with one or more other such poisonous or toxic substance. It is usually regarded as the 'cocktail effect'. On day to day basis, organisms have been exposed to pesticide as well as other chemicals via different route and nobody is aware of the potential damage it might cause if continuously exposed to such substances even at very minimal quantity.

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Check Your Progress

10. Define pesticide.
11. Give one example of an insecticide.
12. How does a fumigant kill insects?
13. What is the cocktail effect?

2.6 INSECTICIDE APPLIANCES

Insecticide/pesticide are applied on crops to keep the pests under minimal biological activity with the help of equipment known as insecticide appliances. Insecticides are applied against insect pests; fungicides are applied against fungal pests whereas herbicides are applied against weeds in order to protect crops as well as to avoid economic losses. For the effective management of crops, it is must to select the most competent/effective equipment for safeguarding a uniform deposit on the target in the minimal time with minimum labour and without substantial wastage of material, i.e., insecticide. The concentration as well as quantity of the spray fluid or dust material to be applied hugely depend upon the type of machinery used. The effectiveness of the equipment/appliance/machine depends upon its ability to give the maximum pest control per unit area and time with the minimum dose of actual ingredient of the poison. Further, it should be noted that both the wastage as well as the pollution of the environment should be kept at minimal. Insecticide/Pesticides may be applied as dusts, sprays, mists, aerosols, smokes, etc. and accordingly there are different types of appliances used for spraying insecticide like dusters, sprayers, agricultural aircrafts, granule applicators, soil injectors, etc. The different types of insecticide appliances used for spraying insecticide/pesticide are as follows:

I. Dusters

Dusters are the equipment which are used to distribute dust formulations. These appliances may either be manually operated or power operated.

1. Manually Operated Dusters

There are different kinds of manually operated dusters that are easily available in the market. A few important types of dusters are as follows:

(a) **Plunger Duster:** It is composed of air pump, dust chamber and a discharge assembly. This kind of manual duster is held by one hand and is pumped with the other hand. The air which is pumped in creates a dust cloud which passes via the delivery vent. The total amount of dust to be applied can be controlled by the speed at which plunger is forced as well as by regulating orifice at the vent. There are several advantages of using a manual plunger duster like it is easy to operate, cheap and is useful for dusting in households as well as kitchen gardens. Plunger dusters are generally used for spot-treatments against insects like ants, poultry pests and external parasites of farm animals.

(b) **Bellows Duster:** It can be easily carried in hand and on the back as well. The air blast is formed by operating the bellows. Bellow dusters comprises a small container for dust, which is fed to the air stream, thus producing a dense cloud.

(c) Rotary or Fan Duster: It consists of an enclosed fan pitched to a hand crank and a hopper which is used for holding the dust. The high-speed gear transmits the velocity to a blower and the dust cloud enters the atmosphere via spreader nozzle. The dust is further carried away by the wind and it falls on the target. These appliances are useful for dusting on crops like paddy growing in standing water. It is used for dusting/spraying of powder forms of pesticides uniformly in crops, nursery, vegetable gardens, field crops, tea and coffee plantations, greenhouses, glasshouses, and warehouses.

(d) Wet Dusting Equipment: In this equipment, as the dust is passing, a fine discharges of water mixe with it before reaching the target. This dust adheres better on the crop surface as compared to the ordinary dust and the drift is also reduced. This kind of appliance is more appropriate for semi-arid zones.

2. Power Operated Dusters

A few important types of power operated dusters are as follows:

(a) Tractor Mounted Duster: It is also referred to as power take off duster. As the name suggests, tractor mounted duster is mounted on a tractor and the power which is required to operate the duster comes from tractor with the help of a V-belt. The dust flows via eight nozzles mounted on a boom. The speed of a fan producing the blast differs with that of the tractor; hence, it is hard to sustain a uniform discharge. This type of appliance can carry up to 20- 45 kg of dust.

(b) Engine-operated Duster: It is operated with the help of an internal combustion four stroke engine of power around 1-3 horse power (hp). Larger dusters having a power around 25 horse power are also available. Engine operated duster can be held in hand, can be carried on the back (backpack type) as well as can be carried on a stretcher or trolley, based on the size and utility of the appliance. In engine operated dusters, fan normally rotates at a speed of around 2,200-3,400 rpm and delivers 14.56-28.00 m^3/min of air at velocities of 80-260 kmph. Engine operated dusters are suitable for dusting trees as well as large fields. Some of the tractor trailor dusters have boomed up to 9 metres with as many as 18 delivery nozzles.

Fig. 2.6 *Backpack Type of Insecticide Appliance*

II. Sprayers

Sprayer refer to an insecticide appliance which atomizes the spray fluid, which might be a suspension, an emulsion or a solution. The fluid is ejected by applying some force for proper spreading/distribution of the insecticide.

***Fig. 2.**7 Insecticide Sprayer*

On the basis of the volume of spray fluid discharged to cover a unit area, sprayers can be categorised as follows:

1. Volume-Based Sprayers

A few important types of volume-based dusters are as follows:

(a) High volume (HV) sprayers: These sprayers require approximately 300-500 litres per ha of spray fluid normally and some-times even up to 800-1000 litres per ha. The amount of fluid requires depends upon the size of the crop. High volume sprayers are the most adaptable/handy/useful sprayers. The size of spray varies between 300-500 μm and the density is approximately 10-20 droplets per cm^2. A large number of sprayers are available in the market, for instance, foot sprayer, stirrup sprayer, knapsack sprayer, hand compression sprayer, rocker sprayer, etc.

(b) Low volume (LV) sprayers: These sprayers require approximately 50-100 litres of spray fluid per ha. They are usually motorized knapsack sprayers. The size of droplets varies from 100-300//m and the density is approximately 30-50 droplets per cm^2.

(c) Ultra low volume (ULV) sprayers: These sprayers require approximately 1-5 litres per ha of spray fluid. Usually, special formulations are available in the market which can be used directly without any dilution. The size of spray droplet varies between 60-100 μm and their density is approximately 50-70 droplets per cm^2. The knapsack mist blowers, with restrictors, are included in this category.

(d) Aerosol sprayer: These sprayers require less than 1.0 litre per ha of spray fluid. Aerosols are generally applied in enclosed places. The size of droplets varies between 1-50 μm and density is approximately 70-350 droplets per cm^2. For instance, pressurised containers, swing fog machine, etc. are included in this category.

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Different types of droplet spectra are adopted for various situations. Majority of the flying insects require very fine spray with the particle size varying between 10-30 µm. For locusts as well as forest insects, a spectrum of 20-60 µm is most appropriate. Most herbicidal sprays have a spectrum of around 400-1000 µm which gives minimum drift. The droplet spectra are usually classified as depicted in the table 2.1.

Table 2.1 *Droplet Spectrum of Various Types of Spray Discharges*

Table 7.2 Droplet spectrum of various types of spray discharges

Size of droplets (µm)	Type of spray	Equipment
400-1000	Coarse spray	Hydraulic sprayer
100-400	Fine spray	Mist blower
50-100	Mist spray	Micron sprayer, ULVsprayers
1-50	Fog spray	Aerosols, Fogging machine
0.001-1	Smoke	Smoke generator
<0.001	Vapour	Vapour generator

Types of Nozzles

Different types of nozzles are used to disperse the spray fluids. Nozzles are generally classified and named after the energy used to form droplets.

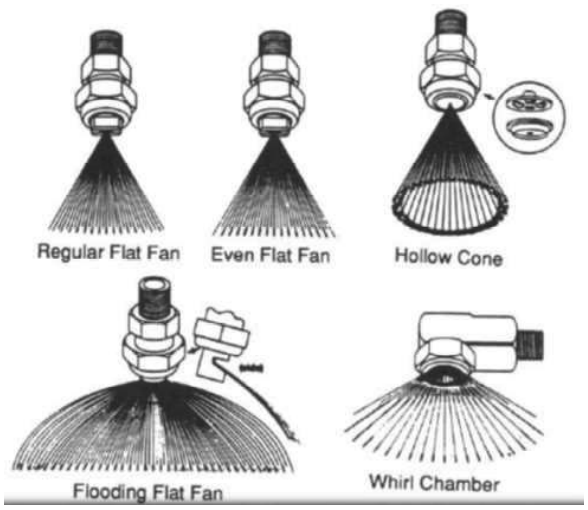

Fig. 2.8 *Kinds of Spray Nozzles*

A few important types of nozzles are as follows:

(i) Hydraulic nozzles: These are primarily used in sprayers where large quantities of water are used in spray fluid. The liquid under pressure is fed via a nozzle. The pressure determines the rate of discharge, throw of the fluid as well as its atomization. Hydraulic nozzles generally produce coarse sprays and are of the following types:

- **Impact or flood jet nozzles:** They operate at low pressures of around 0.5-1 kg per cm^2 giving a coarse spray without any drift. Such nozzles are generally used for spraying herbicides as well as liquid fertilizers.

- **Flat fan nozzles:** These are supplied with variable discharge rates varying from 500 to 3,000 ml per minute at different angles (60-110°). Those most commonly used nozzles have a discharge of around 1,500 ml per min at a pressure of 3 kg per cm^2 and an angle of 80°. Flat fan nozzles also give fine to coarse sprays without much drift and are most appropriate for insecticidal as well as fungicidal spray for a good coverage.
- **Cone nozzles:** Generally, hollow cone nozzles as compared to solid cone nozzles are used for agricultural practices. These are appropriate for the application of insecticides and are broadly used due to their low price.

(ii) Gaseous/pneumatic nozzles: These are generally used with mist blowers. The atomization happens by the impact of air blast on the drop of a pesticide falling with gravity. The ratio of fluid discharge to air is approximately 1 to 1000 times for appropriate atomization. Gaseous nozzles provide fine sprays which are appropriate for low volume spraying.

(iii) Centrifugal nozzles: The spray fluid is fed to a rotating disc and the centrifugal force disintegrates the spray fluid into droplets of very fine size. Centrifugal nozzle is used in rotatory disc ULV sprayers. The size of the droplet is inversely proportional to the speed as well as to the size of the disc.

(iv) Thermal or hot tube nozzles: A fog comprising very fine droplets can be generated by condensing a pesticide which has been injected into a stream of hot gas to shear the liquid into fine droplets which are instantly vaporized. Later on, these vapours condense to form very fine droplets which remain suspended in the air for some time until they finally settle on a surface. This kind of nozzle is generally used for controlling flying insects in enclosed spaces.

2. Manually Operated Sprayers

These types of sprayers are operated by manpower. They are of the following two types:

(a) Pneumatic sprayers: These sprays generate and use compressed air. These can be divided into the following categories:

- **Hand compression sprayer:** The tank is filled with a spray fluid above which there is an air pressure, which is created with the help of a built-in air pump. After all the spray fluid solution is discharged via the nozzle, the air is released even before the tank can be refilled. Subsequently, air pressure drops with the lowering of spray fluid level in the tank, and hence occasional pumping is necessary. Hand compression sprayer are small spray pumps which are appropriate for kitchen gardens as well as in houses. Hand compressor pumps can carry around 0.5-1.0 litre spray fluid. The body of the pump is composed of polyvinyl carbonate or of a metal with an anti-corrosion coating.

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Fig. 2.9 Hand Compression Sprayer

- **Pressure retaining pumps:** Pressure retaining pumps consist of an air chamber which is filled with air under pressure and then the spray liquid is pumped with the help of a charge pump. Due to this continuous and constant pressure at the nozzle, a uniform discharge as well as droplet size is maintained throughout the operation. The lance is also provided with a regulation to have uniform discharge. For instance, in a knapsack battery sprayer, a pressure of approximately 4-5 kg per cm^2 is developed with the help of a pump mounted on the sprayer itself. The capacity of the tank is around 10-20 litres and the spray liquid is discharged at a constant rate.

Fig. 2.10 Pressure Retaining Pump

- **Small pneumatic atomizers:** Small pneumatic atomizers pumps have a small container consisting of approximately 250 ml and there is a pump mounted on it externally. There is a direct fine discharge of spray fluid on working the pump handle. These kinds of appliances are most appropriate for controlling household pests such as mosquitoes, houseflies, etc., by keeping the doors as well as windows shut for a while. Small pneumatic atomizers are composed of polyvinyl carbonate and also of tin metal. The spray fluid should be removed from container after use.

(b) Hydraulic sprayers: It is an equipment that is used to apply insecticides or fungicides to crops on a wide scale in the form of a spray. Hydraulic sprayers are of the following types:

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- **Knapsack sprayer:** The tank of this kind of sprayer is not pressurized, however, it is provided with a shut off regulator. This kind of sprayer has a plunger or a diaphragm pump which is mounted either outside or inside the tank, and is entirely immersed in the spray fluid. Knapsack sprayer is operated with the help of a hand lever under the arm. New models of this kind of sprayer are now armed with solid piston type pumps as a substitute of the plunger type. Continuous pumping is essential to get a uniform discharge. The spray holding capacity of the tank ranges between 15 to 20 litres. One person can work this sprayer independently and can cover one ha of normal crop in one day, with 15-20 refillings. It is a medium volume sprayer, requiring 350-450 litres of spray fluid per ha.
- **Foot sprayer:** It is a high-volume sprayer. Foot sprayer is also referred to as the pedal pump. Foot sprayers work by up and down movements of the foot of an operator. Foot sprayer comprises of a suction outlet but two delivery tubes, lances and nozzles which are handled by two men. Constant pedalling is necessary to develop a continuous pressure of 17-21 kg/cm2. It is also appropriate for tall crops. It needs approximately 500-1000 litres water per ha based upon the growth of a crop. Four persons are required to operate it effectively. Two individuals are required to hold the lances for spray, one individual is required to pedal it continuously whereas the fourth person prepares the spray fluid and also acts as a reliever to the pedaller. With this pump, 2 hectares can be sprayed in a day.
- **Rocker sprayer:** It is also a high-volume sprayer which need 500-750 litres of spray fluid per ha. Rocker sprayer looks similar to the foot sprayer however it is operated with the help of a long hand lever. The pump may be either of single action or of double action type however in both pump types continuous pumping is required for getting a uniform discharge. Rocker sprayer can develop a pressure up to 14-18 kg per cm^2 and can also be used for spraying trees up to 5 m height. Generally, two persons are required for this sprayer and they can cover about 1-2 ha in a single day.
- **Stirrup pump:** It is a high-volume sprayer and is usually called as bucket pump as it is worked after placing it in a bucket full of the spray fluid. The pump may comprise of either a single barrel or a double barrel. The stirrup pump is worked with hand by up and down movements. Stirrup pump can develop a pressure up to 14 kg per cm^2 and can be provided with two delivery tubes, two lances as well as two nozzles. If two lances are present, then in that case four persons are necessary to carry out the spray operations and they can cover 2 ha in a single day. It further requires around 500-875 litres water per ha based upon the size of the crop.

3. Power Operated Sprayers

A few common types of power operated sprayers are as follows:

(a) Mist blower or motorized knapsack sprayer: It also known as motorized knapsack sprayer is a low volume sprayer, however with a restriction in the nozzle. It can be transformed into an ultra-low volume sprayer. A two-stroke petrol engine usually drives the blower; a part of the air also pressurizes the chemical tank. An impeller blows the air via the sprayer nozzle, whereas the solution separately flows from the liquid tank. The fluid gets atomized at the point of contact with the air blow. The capacity of the tank varies from 7-12 litres and the air blast is delivered at the rate of 2.7-9.1 cm^3/ min, at speed ranging from 175-320 kmph. The rate of discharge of spray fluid varies from 0.5 to 5 ml per min. A single person can cover 2 ha in one day, using approximately 125-200 litres spray fluid per ha. The swath width is 4-5 m horizontally and 3-4 m vertically. Trolley mounted mist blowers are also available with a much larger tank, having a capacity of 50 litres.

Fig. 2.11 *Mist Blower Sprayer*

(b) Tractor mounted sprayer: It is driven by the power take-off shaft of a tractor. The sprayer may be mounted on the power lift or on a trailor. It comprises a big liquid tank having a capacity of around 500-600 litre. The swath width is approximately 18 m and may carry about 18 nozzles on a single boom lance. Two individuals are required to operate the spraying and they can cover up to an area of 4-5 ha in a day. The crop should be planted in rows and it should be just as tall as the clearance of body of tractor allows. Tractor mounted sprayer is comparatively less expensive, however, is multipurpose.

Fig. 2.12 *Tractor Mounted Sprayer*

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(c) Power sprayers: They are high volume sprayers and hence can be mounted easily on a stretcher, a wheel barrow, a tractor as well as on a truck. Power sprayers generally have hydraulic pumps of the piston type. The power is supplied with the help of a four-stroke petrol engine. It comprises of one or two delivery hoses. A delivery hose may be 7-30 m long which ends into a hand-operated spray gun with a regulator. Power sprayers operate at pressures up to 56 kg/cm^2 and thus have a discharge capacity of around 6.8 to over 273 litres/min and carry 180-3,600 litres of spray fluid, based on the size of tank as well as that of the engine. The sprayers are generally used for applying pesticides, fertilizers, plant hormones, etc. on shade trees, fruit plants as well as ornamentals.

(d) Ultra low-volume sprayers: They, for the first time, are used in the USA in the year 1962 for controlling the population of grasshoppers. In the year 1964, technical malathion was used successfully at the rates of 850-1125 ml per ha for controlling the population of cotton boll weevil. Since, then a lot of growth and development has been made in this field. The efficiency of these appliances depends upon the regulation of a uniform size of the droplets. If the size of the droplets are larger than 150 µm, then the coverage area will be poor. However, if the size of the droplets are smaller than 30 µm, then they will miss the target and cause serious environmental pollution through drift. In these kind of appliances, small droplets are propelled at a high velocity so that they reach the target after penetrating the air cushion around the surface to be sprayed. In motorized knapsack sprayers, nozzle can be fitted with the help of an appropriate restrictor for ULV spraying. Nowadays, several spinning disc ULV sprayers re available which run effectively on 12-volt battery. The biggest advantage of using ultra low volume sprayers is that is easy to operate and is very convenient too. The droplet falls on a dentate disc spinning at 3,000 rpm.

The final size of the droplet is determined by the speed, the number of dents per unit length as well as the size of disc. Ultra-low volume sprayers majorly use air currents to circulate the droplets however these can also be provided with a blower to force the droplets towards the target. This causes the increases in the penetration of the droplets via the air cushion for reaching the target surface.

The machines are marketed in various models, for instance, overhead sprayer, hand held rotary disc sprayer, chest-mounted rotary disc sprayer, etc. The container can carry up to 1 litre of concentrated ULV formulation which may be enough for one hectare. A large number of modern ULV sprayers are available in the market in which sonic energy is used to break the droplets. The atomizing nozzle uses sound waves to break the spray fluid into fine droplets. The compressed air is passed via the centre of the nozzle into a resonator cavity; such nozzles are known as soni-core nozzles. The sonic-energy field explodes the passing fluid into a mist of size around 50-100 µm. ULV sprayers are very effective sprayer, and is being marketed by Buffalo Turbine Agricultural Equipment Co., New York, USA. It is generally

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recommended to use ULV sprayers in enclosed spaces like a warehouse or a living quarter, for controlling the population of flies, mosquitoes, grain pests as well as other indoor pests. The drift and droplet spectrum can be studied by placing stretched parafilms or manganese oxide-coated plates or cellophane tapes at varying distances from the sprayer. The droplets so collected can be used to determine the density as well as the size of droplets under a microscope, using ocular and stage micrometres.

(e) **Aerosol dispensers:** Aerosol dispensers have metallic containers to bear the pressure of liquefied propellant. The size of the droplet is very small approximately 1-50 μm and the particles remain suspended in the air for a very long duration of time, which is required for controlling the population of flying insects such as flies and mosquitoes. Aerosol dispensers can be used successfully in greenhouses also. Aerosol dispensers are fitted with a delivery tube which usually remains dipped in the pesticide solution. When a button having a small opening is pressed at the top of this tube, the propellant forces its way out along with a fine spray of the pesticide. The propellant most often used is an inert gas, dichlorodifluoromethane (Freon-12) or methyl chloride. Aerosol dispensers for pyrethrum, allethrin, DDT, lindane, DDVP, etc. are easily available in the market. The capacity of an aerosol dispenser is approximately 300-400 g of formulation, however, smaller dispenser having a size of 2-5 kg sizes are also available in the market. Aerosols are used at the rate of 7-14 g/100 m^3 of space, at 5-10 per cent concentration in the dispenser. Other ways of generating aerosols are via centrifugal energy, compressed air or high velocity hot air pulse jet.

Fig. 2.13 *Aerosol Dispenser*

(f) **Smoke generator:** Solid particles in a smoke varies in the range of 0.001 to 0.1 μm. The smoke generally rises to the top and no enclosure remains untreated. Later on, the smoke particles settle down and the crawling insects generally pick up the lethal doses. However, the smoke which is produced by burning the insecticides loses its killing capacity to some degree. For instance, heat reduces the insecticidal capability of DDT and lindane (both are popular insecticide) by approximately 30%. Smoke formulations are prepared by mixing the technical material with some slow burning material.

For instance, DDT or lindane formulated for slow burning consists of around 58-60% technical material, a burning mixture which is formed by mixing sucrose and potassium chlorate (30-40 %) as well as a retardant like clay or diatomaceous earth (2- 10 %). A container containing around 450 g of this mix will burn for 3 minutes, and treat 450 m^3 of enclosed space. These are also commonly known as 'smoke bombs. Smokes are generally used to kill pests of greenhouses, warehouses, industrial establishments and cargo ships.

(g) Vapour generators: Vapour generators are also known as pesticide vaporizers or thermal vapour generators or electric-vaporising devices. Vapour generators are commonly used in enclosed spaces. Mostly hydrocarbon pesticides like DDT and lindane are held in an electrically heated container at a flash temperature which permits slow but continuous vaporization. Vapour generators can convert up to 28 g of pure lindane crystals into vapours in 5 minutes which would be sufficient enough to kill insects in 280 m^3 of space. The vapours act as fumigants.

III. Agricultural Aircrafts

Agricultural aircrafts, for the first time are used in the year 1920 for controlling the pest population. Since then, agricultural aircrafts have been used for applying pesticides in 40 different countries. It is estimated that there are approximately 20,100 aircrafts, which cover approximately an area of 171.4 million hectares annually, worldwide. Agricultural aircrafts enable the rapid and timely coverage of vast areas. Also, they are very economical when covering a large area. Both the fixed wing aircrafts as well as the rotary wing aircrafts (helicopters) have been employed for applying pesticides on field crops, orchards, forests, pastures as well as wastelands. Agricultural aircrafts are also employed most successfully for controlling the population of locust in desert areas.

There are three types of fixed wing aircrafts, which are as follows:

1. **Light aircraft:** Light aircraft are usually monoplanes with a ground speed of around 100-150 kmph. It consists of a single engine of 90-125 horse power.
2. **Medium aircraft:** Medium aircrafts are usually biplanes with ground speed of approximately 130-300 kmph. It has single engine of 100-450 hp.
3. **Heavy aircraft:** Heavy aircraft is a biplane having a ground speed of 150-250 kmph and is generally composed of two engines with each of 125-500 horse power (hp). One of the biggest advantages of using a heavy aircraft is that it helps in maintaining the altitude even when one of the engines fails. It is a necessary factor for low-level operations.

IV. Miscellaneous Appliances

1. **Granule applicator:** It is a machine that applies granular fertiliser, pesticide, such as slug pellets or Avadex, or insecticide. Granular applicators are used for precision application of solids to improve crop yields and quality. Application rates are often controlled electronically to improve accuracy.
2. **Soil injectors:** Most of the soil fumigants are liquids and are applied with the help of soil injectors. Hand-held soil injectors having a capacity around

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2-3 litres are generally used to inject fumigants up to a depth of 15-22 cm, for controlling the population of soil insects as well as that of nematodes. An individual can treat an area around 0.25-0.5 ha in a day by adopting selective spot treatment. Tractor-drawn soil injectors are often used in advanced countries. Soil injectors are usually placed along with the harrow to direct the liquid into the furrow. Soil injectors get the supply directly from a tank which is mounted on the tractor. Similar injectors can be used for applying liquid ammonia in the soil as a fertilizer.

There are numerous soil injectors available in the market which are used to control rat population. These injectors comprise a container which is connected with the help of a plunger pump. There is a rubber tube having a size about 1 m in length attached with the container. When plunger is worked, the air escapes via the tube connected with container. This carries a load of dry fumigant. The rubber tube is inserted in a live burrow and pitted with soil. After injection, the rubber tube is pulled out and the hole is plugged with soil. For controlling the population of rat, the most popular pesticide used is calcium cyanide dust. Cyanide dust on coming with soil moisture releases hydrogen cyanide gas, which is a deadly poison.

Fig. 2.14 *Soil Injector*

Check Your Progress

14. What is the use of dusters?
15. What is plunger duster composed of?
16. How much litres can be sprayed by high volume sprayers?
17. Write the three types of fixed wing aircrafts.
18. Which insecticide appliance is used for precision application of solids to improve crop yields and quality?

2.7 INSECT MIGRATION

The seasonal movement of insects, particularly dragonflies, beetles, butterflies, and moths, is known as insect migration. The distance varies per species, and most of these movements include huge groups of people. Many latitudinal insect migrants, such as agricultural pests, disease vectors, and beneficial species, show large changes in the number of spring migrants reaching temperate zones from year to year. Although it is often assumed that climatic factors in the winter-breeding regions cause this variance, data to support this theory is sparse.

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Migration and movement are not the same thing. Movement refers to moving from one place to other, however, it does not necessarily constitute the migratory behaviour. Insect shows migratory behaviour for several reasons. For instance, a few insect populations disperse, spreading out within a habitat to avoid competition for resources within the population. Insects also exhibit migratory behaviour to extend their home range, or to occupy a larger area of the same or similar adjacent habitat. Entomologists differentiate migration from other types of insect movement. Insect migration refers to the seasonal movement of insects, especially those by species of dragonflies, beetles, butterflies and moths. The distance travelled varies from species to species. In few instances, the individuals that migrate/move in one direction may not return and the next generation may instead migrate in the opposite direction. This is a significant difference as compared to bird migration. All insects move up to some degree. The range of distance travelled varies from a few centimetres for some sucking insects and wingless aphids to thousands of kilometres in the case of other insects like locusts, butterflies as well as dragonflies. Migration involves longer distance movement and these movements are not affected by the accessibility of the resource items. All cases of long-distance insect migration involve winged insects.

It has been observed that migrating butterflies fly within a boundary layer, with a definite upper limit above the ground. These ‘boundary-layer’ migratory insects comprise the larger day-flying insects, and their low-altitude flight is clearly easier to observe when compared to most high-altitude windborne migrants. Several migratory insect species tend to have polymorphic forms, i.e., a migratory from and a resident form. Polymorphic forms have been well observed in both aphids as well as grasshoppers. The migratory phases are distinguished by the presence of well-developed and long wings. In the migratory locusts, there are distinct long and short-winged forms.

Further, energetic cost of migration has been considered with context to life-history strategies of an insect. Research studies indicates that adaptations for migration would be more beneficial/economical for insects that stay in habitats where the availability of resource keeps on changing seasonally. Further, studies have suggested that species living in isolated islands of an appropriate habitats are more likely to evolve migratory strategies. The role of migration in gene flow has also been observed in numerous species. Parasite loads also affect migration of insects which are severely infected are weak and have shortened lifespans. Infection produces an effect which is known as culling due to which migrating insects are less expected to complete the migration.

Migration is generally marked by definite destinations which require navigation as well as orientation. A flying insect requires to make alterations for crosswinds. It has been well established that several migrating insects can sense wind speed as well as direction and accordingly can make appropriate alterations. Day-flying insects majorly utilizes sun for orienting themselves, though, it requires that they compensate for the movement of the sun. Further, migrating insects

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are capable of sensing polarized light. These migrating insects can use polarized light when the sun is obstructed by the clouds. The orientation mechanisms of the nocturnal moths as well as other insects that migrate have not been well researched, yet magnetic signals have been recommended in short distance migrating insects. Thus, migration involves some or all of these specific behaviours or phases:

- **Determined movement away from the current home range**: It involves migration or continuous movement away from the current home range.
- **Movement in a straight line**: Migrating insects show movement in a particular direction as compared to other kinds of movement.
- **Migrating insects are less responsive to stimuli**: Migrating insects concentrate or spend their energy on destination location and hence become less responsive to stimuli in their home range.
- **Change in behaviour pattern:** Migrating insects exhibit a lot of changes in their behaviour especially the reproductive behaviour and feeding capabilities. Insects preparing to migrate postpone their reproductive activities and change their feeding habits. A few insects climb to the top of a tree to assess and make use of the wind currents when they depart. For example, locusts, which are generally solitary insects, become gregarious.
- **Changes in pattern of energy allocation:** Migrating insects show certain physiological deviations, activated by either hormonal or environmental cues. Aphids, which generally lack wings, might produce a winged generation which are capable of flight. Over numerous nymphal instars, gregarious locusts develop long wings as well as dramatic markings. It has been observed that Monarch butterflies enter into a state of reproductive diapause before their long journey to Mexico.

2.7.1 Types of Insect Migration

Insects usually migrate in response to an environmental situation or other factors. The insect migration is of the following types:

- **Seasonal migration:** As the name suggests, it occurs with respect to seasonal changes. For instance, monarch butterflies in eastern North America migrate seasonally.
- **Reproductive migration:** It occurs to or from a separate breeding location. Salt marsh mosquitoes usually migrate from their breeding grounds after emergence of adults.
- **Irruptive migration:** It usually occurs randomly, and most of the time does not involve the entire population. For instance, painted lady butterflies are irruptive migrants. Their migration is often associated with El Niño weather patterns.
- **Nomadic migration:** It involves progressive movement away from the home range, however, not to a specific alternate location. For instance, Locust migration tends to be nomadic in nature.

Some of the common and scientific names of butterflies and moths that migrate regularly are as follows:

- American lady (*Vanessa virginiensis*)
- American snout (*Libytheana carinenta*)
- Army cutworm (*Euxoa auxiliaris*)
- Cabbage looper (*Trichoplusia ni*)
- Cabbage white (*Pieris rapae*)
- Cloudless sulphur (*Phoebis senna*)
- Common buckeye (*Junonia coenia*)
- Corn earworm (*Helicoverpa zea*)
- Fall armyworm (*Spodoptera frugiperda*)
- Gulf fritillary (*Agraulis vanillae*)
- Little yellow (*Eurema (Pyrisitia) lisa*)
- Long-tailed skipper (*Urbanus proteus*)
- Monarch (*Danaus plexippus*)
- Mourning cloak (*Nymphalis antiopa*)
- Obscure sphinx (*Erinnyis obscura*)
- Owl moth (*Thysania zenobia*)
- Painted lady (*Vanessa cardui*)
- Pink-spotted hawkmoth (*Agrius cingulata*)
- Queen (*Danaus gilippus*)
- Question mark (*Polygonia interrogationis*)
- Red admiral (*Vanessa atalanta*)
- Sleepy orange (*Eurema (Abaeis) nicippe*)
- Tersa sphinx (*Xylophanes tersa*)
- Yellow underwing moth (*Noctua pronuba*)
- Zebra swallowtail (*Eurytides marcellus*)

Some of the common and scientific names of dragonflies and damselflies that migrate regularly are as follows:

- Blue dasher (*Pachydiplax longipennis*)
- Common green darner (*Anax junius*)
- Great blue skimmer (*Libellula vibrans*)
- Painted skimmer(*Libellula semifasciata*)
- Twelve-spotted skimmer (*Libellula pulchella*)
- Variegated meadowhawk (*Sympetrum corruptum*)

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Some of the common and scientific names of true bugs that migrate regularly are as follows:

- Greenbug aphid (*Schizaphis graminum*)
- Large milkweed bug (*Oncopeltus fasciatus*)
- Potato leafhopper (*Empoasca fabae*)

2.7.2 Mode of Migration

Let us discuss the mode of migration in different insect orders:

- **Migration in Lepidoptera:** Migration is a well-known phenomenon in both butterflies as well as moths. For instance, the Bogong moth is a native insect of Australia and it has been observed to migrate to cooler climates. Chrysiridia rhipheus commonly known as the Madagascan sunset moth shows mass migration between the eastern and western ranges of their host plant, when they become depleted or unsuitable for consumption. Further, in southern India, it has been observed that mass migrations of several species occur before the monsoon season. In India, approximately, 250 species of butterflies are migratory in nature. These include members of the Pieridae as well as Nymphalidae.

  It has been observed that the monarch butterfly usually migrates from southern Canada to wintering sites in central Mexico during the winter season. In the late winter or early spring, the adult monarchs leave the Trans volcanic mountain range in Mexico to travel towards the north side. Mating happens and females look for milkweed to lay their eggs, generally, first in northern Mexico and then in southern Texas. The egg hatches and caterpillars emerge out which eventually develop into adults. The adult move towards north, where more offspring can go as far as Central Canada until the next migratory cycle. The entire annual migration cycle involves five generations. Another species, Vanessa cardui commonly known as the painted lady is a butterfly whose annual 15,000 km round trip from Scandinavia and Great Britain to West Africa involves up to six generations. Macroglossum stellatarum, commonly known as the hummingbird hawk-moth migrates from Africa and southern Asia to Europe and northern Asia.

- **Migration in Orthoptera:** Locusts like Schistocerca gregaria frequently migrate with the seasons. Occasionally, Short-horned grasshoppers form swarms that will make extended flights. These are frequently irregular and may be associated to resource availability and thus sometimes fails to satisfy the definition of insect migration. Even though, insect species like Schistocerca gregaria (pocust species) make regular seasonal movements in some parts of Africa; remarkably, the species migrates very long distances, as seen in 1988 when swarms flew across the Atlantic Ocean.

- **Migration in Odonata:** Dragonflies are known to be the longest distance insect migrants. In fact, Pantala flavescens is known to be world's longest known distance travelling dragonfly. This species is thought to make the longest ocean crossings among insects, flying between India and Africa on their migrations. Their movements are regularly aided by winds. Several

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species of Libellula, Sympetrum as well as Pantala are well known for their phenomenon of mass migration.

- **Migration in Coleoptera:** Ladybird beetles like Hippodamia convergens, Adalia bipunctata as well as Coccinella undecimpunctata have been observed in large numbers at few locations. In some cases, these migratory movements appear to be made to look for hibernation sites.

2.8 INSECT POPULATION FLUCTUATION AND FACTORS

The biotic potential refers to the maximum growth rate of a population in which there are no restrictions/limitations. In order for a population to reach its biotic potential, it must have unlimited resources, parasites or other pathogens must not exist, and species must not compete with each other. For these reasons, the value is merely theoretical and is never realized. Further, under natural conditions, a population never reaches its biotic potential, as there are numerous biotic as well abiotic factors that limit the indefinite growth of the population. However, if we subtract the environmental resistance from the biotic potential, we will get the real value of the rate at which said population increases. Now, let us understand this with the help of an example.

For instance, a single moth of *Earias vitella* (Bhendi fruit borer) lays about 200 eggs per female. Its life cycle is completed in 1 month.

After 1 month,

Total number of adults = 200

100 males + 100 females

100 × 200 = 20,000 eggs

After 2nd month,

10,000 × 200 = 2,000,000 eggs

After 1 year,

2,000,000,000,000,000,000,000,000 adults

(i.e., 2 followed by 24 zeroes)

If a single moth can produce this much, they will cover 24.32 above earth surface in 1 year. However, in reality only a fraction of progeny completes life cycle due to environmental resistance. Environmental resistance is the physical as well as biological restraints that prevent a species from realizing its Biotic potential.

2.8.1 Factors Affecting Population Fluctuation

Environmental resistance can be of two types namely abiotic factors and biotic factors. Let us discuss them in detail.

I. Abiotic Factors

Abiotic factors are the non-living components of the eco-system. They are as follows:

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- **Air:** It consists of gases like oxygen, carbon-dioxide, nitrogen, sulphur dioxide, etc.
- **Water/moisture/humidity:** It involves ground water, surface water or water in the well, rivers, oceans, ponds, etc. Moisture/relative humidity is required for metabolic reactions and transportation of salts in insects. Lack of moisture leads to dehydration or death of insects, whereas excessive moisture can be harmful. Deficiency or excess of water affects the normal development as well as activity of insects. It also encourages the disease-causing pathogens. Further, rainfall is must for normal emergence of adults from pupa of several insects like cutworms, *Helicoverpa armigiera* and *Spodoptetra litura*. However, excessive rainfall, causes white grubs to come about of environment where they are subject to predation. Excess rainfall also control the population of aphids and Diamond blackmoth.
- **Wind:** Air that is moving across the surface of earth is called wind. Winds aid in dispersal of insects from one place to other. However, it interferes with the normal physiological processes of insects like feeding, mating and oviposition. For instance, Aphids, mites (Eriophyid mites also) disperse through wind and Helicoverpa flies can fly up to 90 km with the aid of winds.
- **Soil:** It is the upper layer of earth that may be dug or ploughed and in which plants grow i.e., in short, the surface of the earth supporting plant and animal life.
- **Sunlight:** Sunlight is essential for proper functioning of the living organisms on earth as well as for maintaining the optimal temperature on earth's surface, light is essential for the plants to carry out the process of photosynthesis. For instance, lack of proper light in the deeper ocean prevents photosynthesis meaning that the majority of the life in the ocean lies near the surface. Differences in daylight impact temperatures at the equator and the poles. Further, day-night rhythm of the light impacts life patterns including reproduction for all living organisms. Hence, sunlight is one of the most crucial abiotic factors affecting many aspects of the insect life. A lot of vital phenomena of the insect biology like feeding, growth, development, diapause, survival and ethology are greatly affected by light. For instance, in *Bombyx mori*, long day during embryonic development causes adult to lay eggs at diapause stage. Seasonal dimorphism has been observed in aphids due to change in photo period. Short day produces sexual forms whereas long day produces asexual parthenogenetic forms. It has been observed that many species of insects are not equally active throughout the 24 hr of the day. A few insect species are active during the night time (nocturnal), whereas others are active during the day time (diurnal) and still other which are referred to as crepuscular (dusk active) are active mainly at dawn and dusk. Photoperiods also influence growth, metabolism and daily rhythm of activity (feeding, flying, mating and oviposition).
- **Salinity:** It maintains ionic balance which is essential for the survival of the organisms. Animals, in the ocean, are adapted to the salinity via salt renal

gland to control the salt content of their bodies. Plants also have internal provisions to remove excess salt taken from the soil.

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- **Temperature:** On the earth's surface, a constant temperature is maintained by sunlight. Warm-blooded animals like mammals have an internal mechanism to maintain a constant body temperature. Extreme temperature (either low or high) that goes beyond an organism's tolerance may harm or kill the organism. Insects are poikilothermic and hence they do not have any mechanism to regulate the body temperature. The body temperature depends on environmental factors. Normal physiological and metabolic life activities go on smoothly at a specific temperature (or) at a specific range of temperature. This is called the optimum temperature. Insects survive, thrive, grow and reproduce comfortably at this temperature. The rate of chemical reaction within tissues is modified by temperature. Metabolic processes are influenced by temperature and increase with it up to a maximum and suddenly decline at the upper lethal temperature. The upper lethal limit is 40-50^{o}C (even up to 60^{o}C survival in some stored product insects) and lower lethal limit is below freezing point. At low temperature (winter), insects take more days to complete a stage (larval or pupal stage). However, at high temperature (summer), it takes less time to complete a stage. A few insects, when exposed to extremes of temperature, undergo aestivation (during summer) or hibernation (during winter). During this period, there is a temporary developmental arrest known as diapause stage in which all metabolic and physiological activities are suspended. When temperature is favorable, they resume activity. Eggs undergo aestivation in summer. Larva, pupa commonly undergo hibernation in winter. Temperature is an important factor in the life history of insects.
- **Water current:** Standing or stagnant water helps in the multiplication of insect like mosquitoes. On the other hand, running streams are preferred by black flies and caddish flies.

II. Biotic Factors

A lot of biotic factors contributes to population fluctuation in insects. Let us discuss these factors in detail.

- **Presence of food:** As we know that insects are heterotrophic creatures and hence cannot synthesize their own food. They depend on plants for nutritional requirements. The quantity as well as quality of food/nutrition plays an essential role in survival, longevity, distribution, reproduction and speed of insect's development.
- **Biotic interactions:** Insects not only interact with each other but also with other population. These interactions may be positive or negative depending on whether it produces beneficial or harmful effects on the interacting individual or population and thus affects the population of insects. This relationship is known as symbiosis. The term 'symbiosis' refers to as an evolved interaction or close living relationship between organisms from different species, usually with benefits to one or both of the individuals involved. Symbioses interactions are of the following two types:

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- **Obligate symbiosis:** In this symbiosis, the two species are so interdependent on each other that either of the species is unable to survive without the other. Obligate symbioses are usually evolved over a long period of time.
- **Facultative symbiosis:** In this symbiosis, the interacting species engage in a symbiotic partnership via choice, and can survive individually if needed. Facultative symbioses may evolve into obligate symbioses during the course of evolution.

Some of the symbiotic relationships include mutualism, commensalism and amensalism. Let us discuss them in detail.

(a) Mutualism: It is a form of symbiosis wherein both the interacting species benefit from the interaction. This benefit can be in terms of fitness gain, strength gain, free food, free accommodation, etc. for either one or both the interacting species. Thus, mutualisms can take the form of resource-resource relationships, service-resource relationships, or service-service relationships. It is of the following types:

(i) Resource-resource mutualisms: It is also referred to as 'trophic mutualisms' happens via the exchange of one resource for another between the two interacting species involved. Resource-resource kind of mutualisms most often occur between an autotrophic species, i.e., species which are capable of producing their own food from inorganic raw materials by the process of photosynthesis (basically a photosynthesizing organism) and a heterotrophic species, i.e., species which are dependent upon autotrophs for their food supply as they cannot synthesize their food directly using the solar energy (basically an organism which must absorb or ingest food to gain energy).

(ii) Service-resource mutualisms: It happens when the symbiotic species provide a service in exchange for a resource reward. A well-known instance depicting such symbiotic association is the exchange between plants and their pollinators. The pollinator (like insects, birds, moths and bats) visits the plants to gain a supply of energy-rich nectar. This provides the plants with the service benefit of being pollinated as their pollen grains gets attached to the hairs, antennae and other structures of insect while it is taking nectar from the plant. This ensures the widespread distribution of the pollen grains for plants, whereas the insect gets the free energy rich food. This kind of service resource mutualism not only ensures the distribution of pollens but also the phenomenon of cross-pollination as described in Figure 2.15.

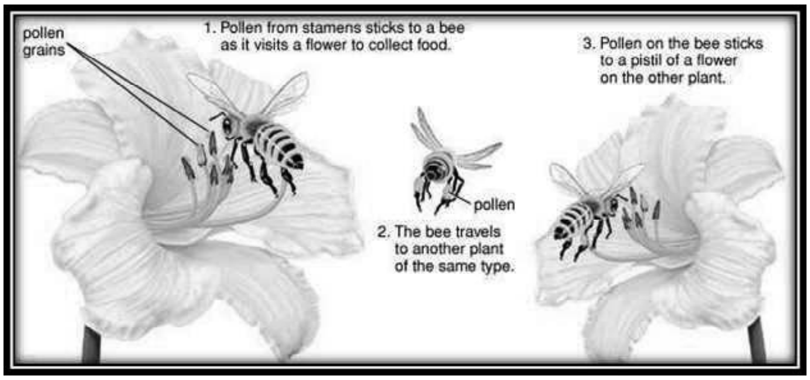

Fig. 2.15 *Phenomenon of Cross Pollination*

(iii) Service-service interactions: It is one of the rarest forms of symbiotic interactions. As the name suggests, both the interacting species receive a service, like shelter or protection from predators.

(b) Commensalism: It refers to a symbiotic association where one species is benefitted from, and is often entirely dependent on the other for resources like food, shelter, or locomotion, with no noticeable adverse or beneficial effects on the host.

(c) Amensalism: It is contrary or opposite to commensalism. This occurs when one species is inhibited or damaged by the presence of the other species. Amensalism may involve competition, where a larger, more powerful, or environmentally better adapted organism excludes another organism from its food source or shelter; for instance, one plant shades out another plant while growing at its normal speed as well as height. On the other hand, antibiosis, refers to the phenomenon where one organism secretes chemicals as by-products that kill or damage the other organism, but do not benefit the other, can be seen commonly in nature. Antibiosis refers to adverse effect of the host plant on biology, i.e., growth, survival, development or reproduction of insects as well as of their progeny. It could occur due to the presence of toxic substance in the host plant; due to absence of essential substances in the host plant or due to the presence of such enzymes in the host plant which affect the digestion of insects. On the contrary, antixenosis occurs when there is non-preference for the resistant plant compared to a susceptible one.

(d) Parasitism and predator-prey relation: Parasitism refers to the non-mutualistic form of symbiosis that occurs when one of the organisms benefits at the cost of the other. However, unlike predation, parasitism does not essentially/certainly lead to the death of the parasitized organism, and is usually, imperative to the life cycle of the parasite to keep its host alive. Occasionally, the parasitized host is killed due to parasitic invasion; in this case, the invader is referred to as a parasitoid. Parasitism may involve direct infiltration of the host body to feed off tissue, influencing behaviours that benefit the parasite, or kleptoparasitism, in which the parasite steals food or other resources from a host. Parasitic symbiosis seems in numerous forms;

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few are rather non-threatening, for instance, ectoparasites, like fleas, which feed off the blood of larger animals and may cause uncomfortable itching. However, the ectoparasite may act as a carrier or vector, which transmits intercellular endoparasites such as bacteria and viruses to the host, often causing significant damage or death. Parasites like fungi, bacteria, protozoa, nematodes and various arthropods, and predators like birds, mammals, reptiles, and amphibians keep the insect population in check. Interaction between predator and prey are different from the parasite and host relationship. The predator prey relationship comprises the interactions that happen between two species and their subsequent effects on each other. In the predator prey relationship, one species feeds on the other species. The prey species represent the animal that gets killed whereas the predator species represent the animal that kills the prey. The predator prey relationship develops over time as many generations of each species interact. In doing so, they affect the success and survival of each other's species. Similarly, the host parasite relationship is completely dependent on the interaction between two species. The interrelationship between the parasite and host populations incorporates with the infection level. Parasite lives comfortably inside or outside the host body. It extracts its nutritional requirement from the concerned host. The life cycle of parasitic insect includes specific host. Growth, survival as well as development of these parasitic insect depend upon the availability of specific host. It has been hypothesized that a parasitic kind of symbiotic association might have developed/evolved from other, more giving/beneficial forms of symbioses; one species may begin to exploit a former mutualistic relationship by taking more of a resource or service than is returned, or by not contributing benefits to the other interacting species at all.

Fig. 2.16 *Parasitic Association between Bed-Bugs and Human Skin*

(e) Competition: Competition between the members of same species or different species occurs for limited food, space, mate (between members of same species). Accordingly, competition can be inter-specific or intra-specific. Inter-specific competition refers to the competition between individuals of the different species. This type of competition occurs mainly for limited food and space. Limited food supply also affects parasitoids and predators of insect hosts. Intra-specific competition refers to the competition between the individuals of same species. This type of competition occurs for food, space as well as for mate.

It can be concluded that all the biotic and abiotic components of the ecosystem are closely interlinked with each other and thus there is a continuous flow of energy from abiotic to biotic components through different trophic levels arranged in the form of pyramid. Further, this helps in maintaining the population of species.

Check Your Progress

19. Which insects utilize the sun for their orientation?
20. Give one example of reproductive migration.
21. Name the world's longest known distance travelling dragonfly.
22. What are the abiotic factors responsible for fluctuations in insect population?

2.9 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Biological control refers to the action of natural enemies like parasites, predators as well as pathogens in maintaining another organism's population density at a lower level in nature than would occur normally in their absence.
2. Ectoparasite is a parasite that lives on the outside of its host, for example, larvae of parasitic Hymenoptera and Diptera. On the other hand, endoparasite is a parasite that resides inside the body of the host to fulfil its nutritional requirements.
3. In 1941, Aphelinus mali introduced from USA for controlling Eriosoma lanigerum (wolly apple aphid).
4. This effect is also known by other names such as delayed sterility, F1 sterility or partial sterility.
5. This phenomenon is generally applied on insects belonging to the order Lepidoptera and Hemiptera that contain polycentric chromosomes.
6. Cytoplasmic Incompatibility (CI) refers to the phenomenon that results in gametes, i.e., sperm and eggs being unable to form viable offspring.
7. One of the classic example of insecticide resistance has been observed in housefly (*Musca domestica*).
8. The different types of resistance an insect can develop to insecticides are metabolic resistance, altered target-site resistance, behavioural resistance and penetration resistance.
9. Integrated Pest Management (IPM) refers to the collective methods used for controlling pest. It employs all appropriate methods of pest control to decrease pest populations and maintain them below economic injury level.
10. A pesticide refers to a substance or to a mixture of substances which are used for killing pests i.e., organisms capable of destroying cultivated plants or animals.

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11. Sevin is one example of an insecticide.
12. A fumiginat is a pesticide that is used to kill insects that inhale toxic vapours of the chemical. For example, Phostoxin.
13. The major concerning issue regarding exposure to pesticides is the fact that the effects of individual chemicals can be enhanced or altered when combined with one or more other such poisonous or toxic substance. It is usually regarded as the 'cocktail effect'.
14. Dusters are the equipment which are used to distribute dust formulations. These appliances may either be manually operated or power operated.
15. Plunger duster is composed of air pump, dust chamber and a discharge assembly.
16. High volume sprayers require approximately 300-500 litres per ha of spray fluid normally and some-times even up to 800-1000 litres per ha.
17. The three types of fixed wing aircrafts are light aircraft, medium aircraft, heavy aircraft.
18. Granular applicators are used for precision application of solids to improve crop yields and quality.
19. Day-flying insects majorly utilizes sun for orienting themselves, though, it requires that they compensate for the movement of the sun.
20. Reproductive migration can be seen by salt marsh mosquitoes as they usually migrate from their breeding grounds after emergence of the adults.
21. Pantala flavescens is known to be world's longest known distance travelling dragonfly.
22. Air, water, sunlight, wind, soil, salinity, temperature and water current are the abiotic factors responsible for fluctuations in insect population.

2.10 SUMMARY

- Biological control refers to the action of natural enemies, such as parasites, predators as well as pathogens in maintaining another organism's population density at a lower level in nature than it would occur normally in their absence.
- The different kinds of parasitism are superparasitism, hyperparasitism and multiple parasitism.
- Genetic control of insect pest involves the procedure of manipulating genetic material of a pest species so as to confer lethality on the species.
- Genetic manipulation can also be achieved by incorporating new and potentially deleterious genes (or alleles) into the genetic makeup of pest population.
- Genetic control of the insect pest includes several techniques, namely insect sterilization, conditional lethal mutation, cytoplasmic incompatibility, behavioural changes, hybrid sterility, simply inherited mutations, double stranded RNA mediated inhibition and reciprocal translocations.

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- Insecticides belong to different classes, namely organophosphates, carbamates, pyrethroids, neonicotinoids, etc.
- The primary role of an insecticide is to kill an insect via a specific mode of action, or somehow inhibits the growth of insects.
- Generally, insects exhibit resistance to a variety of insecticides with the same mode of action.
- Insect populations can develop resistance to insecticides in several ways and pest population may or may not employ more than one mechanism simultaneously.
- The types of insect resistance are metabolic resistance, altered target-site resistance, behavioural resistance and penetration resistance.
- The term pesticide is a general term which applies to numerous chemicals like insecticide, fungicide, herbicide as well as nematocide.
- Bioaccumulation refers to the entry of a pollutant or toxic/hazardous substance in the food chain while biomagnification is defined as the increase in concentration of a toxic substance at each successive trophic level after entering into food chain.
- Each country adopts their own agricultural policies as well as Maximum Residue Limits (MRL) and Acceptable Daily Intake (ADI).
- Crop protection chemicals, i.e., pesticides are an essential constituent of agriculture as they play a major role in protecting the crop as well as other produce from pests and hence increase the productivity of the farm.
- Capacity building refers to an investment in the future sustainability of a project.
- Pesticide residues are detected in vegetables, fruits, pulses, cereals as well as other food commodities after their pre-harvest or post-harvest application.
- Pesticides are toxic and exposure to pesticides can lead several health issues. They are associated with serious illnesses and are capable of causing diseases ranging from respiratory problems to cancer.
- Insecticide/pesticide are applied on crops to keep the pests under minimal biological activity. Insecticides are applied against insect pests; fungicides are applied against fungal pests whereas herbicides are applied against weeds in order to protect crops as well as to avoid economic losses.
- Major insecticide appliances are dusters, sprayers, agricultural aircrafts, granule applicators, soil injectors, etc.
- The seasonal movement of insects, particularly dragonflies, beetles, butterflies, and moths, is known as insect migration.
- The types of insect migration are seasonal migration, reproductive migration, irruptive migration and nomadic migration.
- The biotic potential refers to the maximum growth rate of a population in which there are no restrictions/limitations.

2.11 KEY TERMS

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- **Biological Control:** It, often known as bio-control, is a way of using other organisms to control pests such as insects, mites, weeds, and plant diseases.
- **Parasite:** It is an organism that lives in or on another species' organism (its host) and benefits from the nutrients obtained at the expense of the other.
- **Predator:** It is an animal that preys on other animals in its native habitat.
- **Genetic Control:** It refers to control done by creating insect strains by genetic manipulation to carry features that are harmful to the species in their natural environment.
- **Insect Sterilization:** It is a process for birth control in which released, radiation-sterilized males inseminate wild female pest insects, preventing them from reproducing.
- **Insecticides:** These are the substances that are used to kill insects.
- **Insecticide Resistance:** It refers to an insect's ability to endure the poisonous effects of an insecticide to the point where it can no longer be controlled with that chemical.
- **Pesticides Residues:** It refers to the pesticides that remain on or in food after being applied to food crops.
- **Insecticide Appliances:** These are the appliance or equipment used to spray pesticides or insecticides.

2.12 SELF-ASSESSMENT QUESTIONS AND EXERCISES

Short-Answer Questions

1. Differentiate between superparasitism and hyperparasitism.
2. How are biological control strategies practiced?
3. Discuss briefly the advantages and disadvantages biological control of insect pest.
4. What are the reasons responsible for the failure of insect control measures?
5. Classify pesticides according to pests they control.
6. Mention the types of insect migration.

Long-Answer Questions

1. Describe the techniques used for genetic control of insect pests.
2. Explain the mechanism of different types of insecticide resistance.
3. Discuss the different types of insecticide appliances used for spraying insecticide/pesticide.

4. Discuss the principles of pesticides residues and their hazards in India.
5. Analyse the factors responsible for population fluctuation in insects.

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2.13 FURTHER READING

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UNIT 3 INSECT PESTS

NOTES

Structure

3.0 INTRODUCTION

A pest is any animal or plant harmful to humans or human concerns. The term is particularly used for creatures that damage crops, livestock, and forestry or cause a nuisance to people, especially in their homes. Humans have modified the environment for their own purposes and are intolerant of other creatures occupying the same space when their activities impact adversely on human objectives. Insect pests cause significant damage to agricultural products intended for human foods and animal feeds. In addition to direct losses caused by insects to plant systems, fruits, and seeds, these biotic agents cause indirect losses because they leave important contaminants such as body parts or exoskeletons, insect eggs, and off-odors on produce. There are more than six million species of insect although only 20–30 of these are important pests for major crops. The key for the proper insect pest management is to understand their biology and behavior, the kinds of damage they produce, and application of proper integrated pest management in order to achieve a crop production system that optimizes the use of natural resources, protects the environment, and maximizes output in a sustainable way. Humans have traditionally performed pest control in agriculture and forestry by the use of pesticides; however, other methods exist such as mechanical control, and recently developed biological controls.

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In this unit you will study about common insect pests and their life cycles, management strategies and tools to control insect pests, and insects of medicinal and veterinary importance.

3.1 OBJECTIVES

After going through this unit you will be able to:

- Understand common insect pests and their life cycles
- Analyze management strategies and tools to control insect pests
- Explain insects of medicinal and veterinary importance

3.2 LIFE CYCLE OF COMMON PESTS AND THEIR CONTROL MEASURES

3.2.1 Pests of Cotton

1. Cotton Semilooper, *Tarache notabilis (Walker)* (Lepidoptera: Noctuidae):

This insect is seen throughout the plains of Pakistan as well as India as a minor pest of cotton, however, in certain years, it assumes a serious form. Apart from cotton, this pest also feeds on the leaves of sonchal (*Malva parviflora*), brinjal, etc. The fully-grown caterpillars is about 40 mm in length and dark green in colour, possessing six pairs of black and bright- yellow spots on the back. As they move, they bend the body, forming half loops and therefore known as semi- looper. The adults of this pest are heavily built, white moths, with projecting grey and brown spots on the wings, measuring approximately 30-32 mm across. The pest remains active from the month of April to October and passes through the winter season as a hibernating pupa. The moths appear in the months of March-April and are active during night time. This pest lay green, rounded eggs singly, on the underside of leaves. The eggs hatch in a time span of 2-4 days and the caterpillars immediately begin feeding hungrily. Once fully fed, they descend to the ground, where they construct earthen cells at a depth of around 3 cm for undergoing pupation. They emerge as moths in a time span of 5-14 days and are short--lived. The life-cycle is completed in 16-34 days. By the month of October-November, they complete 4-5 generations. The parasitoids associated with larvae of this pest are *Actia monticola Mall*, and *Exorista seviloides Bar*. (Tachinidae). The caterpillars feed on cotton leaves and skeletonize them altogether. In years of heavy infestation, the plants may be completely denuded of leaves. Infestation can be minimized by ploughing the fields soon after cotton harvest or by growing clovers in rotation with this crop. It can be controlled chemically also by applying insecticdes and pesticides. Figure 3.1 is depicting the life stages of *Tarache Notabilis*.

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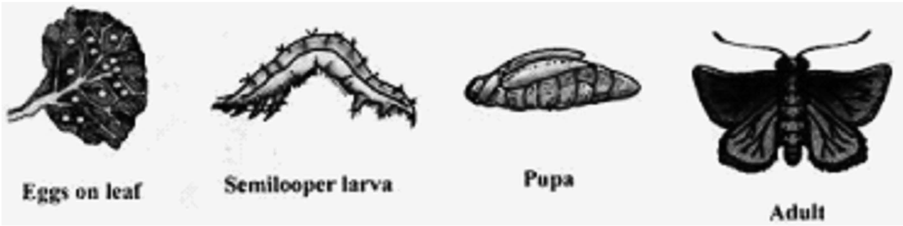

Fig 3.1 Life Stages of Tarache Notabilis

2. Green Semilooper, Anomis Flava (Fabricius) (Lepidoptera: Noctuidae):

This pest is widely distributed in the cotton growing areas of Africa, Asia as well as Australia. In India, it is a sporadic pest of cotton and occasionally pose a serious threat to the crop especially in Gujarat and Rajasthan areas. Apart from cotton, the larvae of green semilooper also feed on *Hibiscus esculentus L., Hibiscus cannabinus L.*, and *Phaseolus radiatus L.* among the cultivated plants and on *Hibiscus rosasinensis L., Sida cardifolia L., Althaea rosea CAV., Bombyx malabaricum DC*. and *Malachra capitata L.* among the forest trees. The fully grown larva is approximately 25-30 mm in length and is pale- yellowish green in colour with five white lines arranged longitudinally on the dorsal surface. The adult is an attractive, small moth with reddish-brown fore wings traversed by two darker zig-zag bands. The hind wings are pale brown in colour. The emergence of adult moths overlaps with the warming up of the season. The adult female of green semilooper lays approximately 600 eggs on leaves during an opposition period of 8-12 days. The eggs hatch within a time period of 4-5 days. The larvae which move around with a specific semi-loop crawl and feed on leaves. The entire development completes within a period of 18 to 20 days and the larvae undergoes through 5 instars during this period. They make a loose cocoon before pupation, either within the leaf folds or among debris in the soil. The pupal period lasts approximately for 8-9 days. The life span of the moth varies between a period of 12-13 days and the entire life-cycle is completed within a period of 4-6 weeks. More than one generation is completed in a crop season. The young larvae collect in small groups and move actively and feed on leaf lamina making small punctures. The grown-up larvae feed voraciously on the entire leaves, leaving only the main veins. The caterpillars also eat the tender shoots, buds as well as bolls. Due to heavy infestation the plants may get entirely defoliated. Figure 3.2 is depicting the life stages of green semilooper.

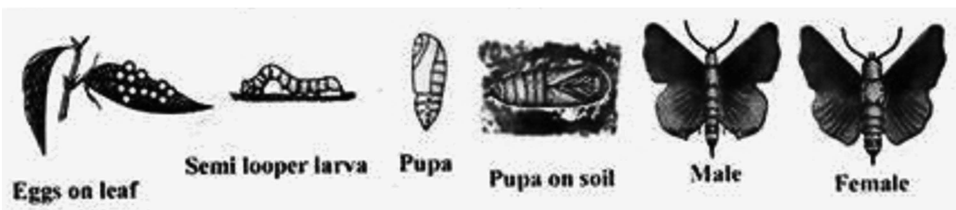

Fig. 3.2 Life Stages of Green Semilooper

3. Bud Moth, *Phycita infusella* (*Meyrick*) (Lepidoptera: Pyralidae):

This insect pest is distributed throughout India as a minor pest of cotton and pose serious threat on desi varieties as compared to American varieties. It is infrequent in existence and thus pose serious threats only in certain localities. Apart from cotton, it also feeds on okra as well as other allied plants. In the caterpillar stage,

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it makes distinguishing webbings around the terminal young growth of leaves, where it feeds. The fully-grown caterpillars are greenish in colour having a length of approximately 13-16 mm long, having a black front and faint brown stripes on the rest of the body. The adult is a greyish-yellow moth, spotted with fuscous, and measures around 20 mm in length across the wing expanse. The front wings are faint yellow in colour at the base with red wavy lines and the hind wings are white in colour, with brown marginal lines. The pest is active from the months of April to October and passes the entire winter season as a hibernating caterpillar in debris on the ground. The moths appear in the month of April and lay small rounded eggs on tender leaves of cotton or other host plants. The eggs hatch in about 7 days and the young larvae begin feeding on bud or young leaves. As the larvae grow, they web together the terminal leaves with silken threads and feed inside. Once fully fed approximately after 21 days, they create silken cocoons in the midst of twisted leaves. The pupal stage lasts for a period of 11 days and the moths, on emergence, live for a few days only. The entire life-cycle of this pest is completed within a period of 5-6 weeks and the pest completes 4-5 generations in a year. *Bracon brevicornis Wesmael* and *B. kitcheneri Will*. (Braconidae) are associated with larvae of this pest. Due to the webbing of leaves as well as due to feeding by the caterpillars, additional growth of the plants gets inhibited. The attacked leaves weaken away, dry up and drop off. The flowering as well as fruiting are very poor and the reduction in production is substantial. One of the control measure is to spray 2.0 kg of carbaryl 50WP in 315-375 litres of water per ha.

4. *Spodoptera litura* (*Fabricius*) (Lepidoptera: Noctuidae)

Spodoptera litura, commonly known as oriental leafworm is a polyphagous noctuid moth. It is also known by several other names such as the Egyptian cotton leafworm, tobacco leaf caterpillar, cluster caterpillar, common cutworm, armyworm, cotton leafworm, tobacco budworm, tobacco cutworm, cotton worm, rice cutworm and tobacco caterpillar.

The taxonomic classification of *Spodoptera litura*:

- **Kingdom**: Animalia
- **Phylum**: Arthropoda
- **Class**: Insecta
- **Order**: Lepidoptera
- **Family**: Noctuidae
- **Genus**: *Spodoptera*
- **Species**: *litura* (Fabricius, 1775)

Female moths oviposit on a broad range of host plants. Eggs are always laid in batches, spherical in shape with colour ranging from whitish yellow to pale orange-brown. Egg masses are covered with hairy scales and measure about 4-7 mm in diameter (Miyahara et al., 1971). Eggs hatch in 4-5 days at optimal temperature (25 ± 2 ^{o}C) and relative humidity (70-75%) conditions. *S. litura* passes through six larval instars with body length of the larvae increasing from 2.3 mm to 40 mm. Young instars are pale green in colour and feed in groups. However, as the larvae grow in size, they disperse or spread to other leaves or plants. Late instars are dark green to brown in colour having a characteristic yellow longitudinal stripe along the length of the dorsal surface. A parallel row of black spots are present laterally on each side of this strip. On an average, a larva passes through its six stages in 15-23 days under favourable conditions. The pupa is reddish-brown in colour, having two spines at the tip end of the abdomen and measures up to 15-20 mm. Adults have grey-brown body colour and measures up to 15-20 mm in length with a wing span of 30-38 mm. The forewings are grey-brown in color with white oblique bands while hind wings are pale with brown margins. The complete life cycle of *S. litura*, on an average is completed in 25 days (EPPO, 1990). Life cycle of *S. litura* larvae is shown in Figure 3.3.

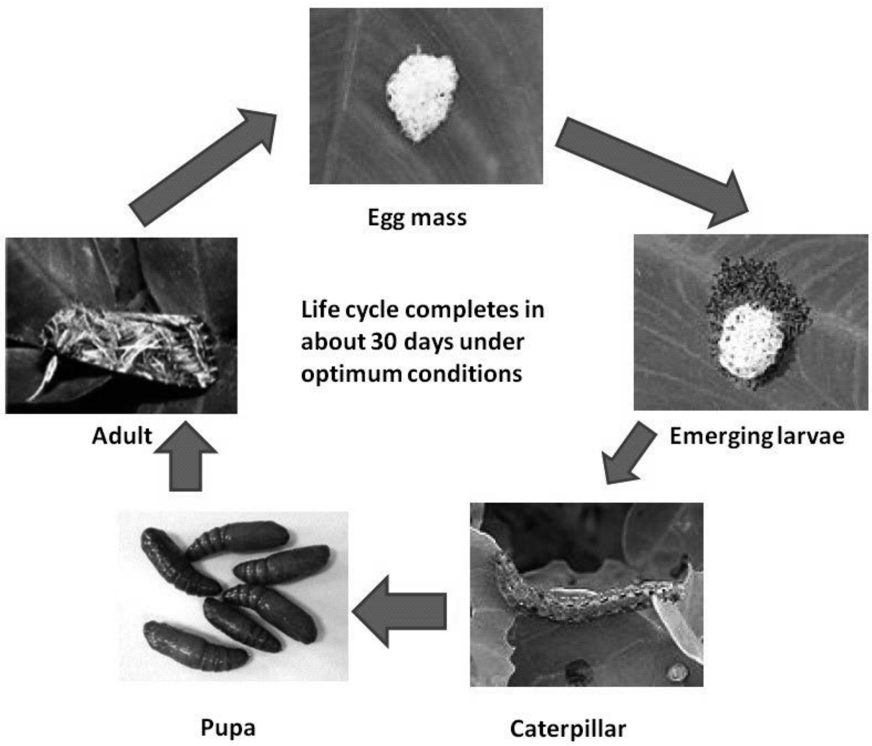

Fig.3.3 *Life Cycle of S. litura Larvae*

(*Source:* Adapted from Wikipedia)

Spodoptera litura is widely distributed in Australasia, Pacific Islands and throughout tropical and temperate Asia (Feakin, 1973; Kranz et al., 1977). It is widespread in countries like Bangladesh, Hong Kong, India, Japan, Malaysia, Philippines, Burma, etc. The worldwide distribution is attributed to its ability to feed on a variety of crops and also adapting to diverse climatic conditions. However, *S. litura* has restricted distribution in Russian Federation, Russian Far East, French Polynesia, New Zealand, Wallis and Futuna Islands, New South Wales, Queensland, Western Australia, etc. whereas it is known to be eradicated in other parts of the world including Germany, Netherlands, etc. (EPPO, 2013). It mostly inhabits cultivated land, plantations, orchards, riverbanks and wetlands. It is a polyphagous agricultural pest and host range includes around 120 species of vegetable crops (Moussa et al., 1960). It majorly infests plants at flowering, fruiting or vegetative growth stage. The major attacked species include crops of economic

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importance like cotton, jute, tea, tobacco, groundnut, maize, rice, soybeans, flax, groundnuts and vegetables like cucurbit, *Phaseolus*, *Brassica*, sweet potatoes, potatoes, capsicum and species of vigna. Apart from these, other host plants include weeds, ornamental plants, wild plants and various shade trees (Brown and Dewhurst, 1975; Holloway, 1989). Most of the plant damage is caused due to excessive feeding by larvae. The loss recorded in crop yield due to infestation of *S. litura* was huge. For instance, a study reported around 43.7% and 27% reduction in groundnut haulm and pod yield respectively on infestation with 12 egg masses of *S. litura* (Panchabhavi and Raj, 1987). Thus, various control measures have been adopted till date to control this pest. Initially, several insecticides were used to control *S. litura* population and this strategy proved to be successful, but later the pest developed resistance to most of the insecticide including cypermethrin, fenvalerate and quinalphos (Ramakrishnan et al., 1984). Biological practices such as the release of egg and larval parasitoids in agricultural fields have achieved only partial success in the past (Patel et al., 1971; Michpl et al., 1984). In Gujarat, five weekly releases of 50,000 *Chelonus heliopae* egg-larval parasite and two release of 15,000 *Telenomus remus*, an egg-larval parasitoid per 0.2 ha against *S. litura* in *Brassica oleracea* resulted in 60% parasitism (Patel et al., 1971). However, *Telenomus remus*, alone was effective only against compact *S. litura* egg masses (Braune, 1982). Apart from them, *Serratia marcescens*, a bacterium was found to be effective against *S. litura* (Ansari et al., 1987). *Bacillus thuringiensis* was found to be a highly valuable microbial insecticide against *S. litura* (Zaz and Kushwaha, 1983). Recently, the focus has been on Integrated Pest Management (IPM) that integrates various environment sensitive technologies to suppress pest populations. IPM includes release of natural enemies in agricultural fields, using neem extract during early stages of plant growth, pheromone traps, manually removing egg masses and killing the larvae, spraying insecticide on observing initial leaf damage followed by repeated exposure to insecticide after 10 days, effective and controlled spraying of nuclear polyhedrosis virus suspension at regular intervals for controlling *S. litura* population (Chari et al., 1985; Krishnaiah et al., 1985).

5. Cotton Grey Weevil, *Myllocerus undecimpustulatus Faust* (Coleoptera: Curculioniaae):

Cotton grey weevil is found throughout India and is a minor pest of cotton, especially of the desi cotton varieties. Apart from cotton, it feeds on cultivated plants like bajra (*Pennisetum typhoides*), maize, sorghum, guava, arhar (*Cajanus cajan*), groundnut, etc. The plants are attacked by the weevils which are projecting above the ground level and the grubs which feed on the underground parts. The weevils are grey in colour and are 3-6 mm in length. The grubs are white in colour, legless, and cylindrical in shape having a length of around 8 mm. The pest remains active from the month of April to November and passes the winter season in the adult stage hidden in debris. The weevils appear in the month of April-May and lay ovoid shaped, light yellow-coloured eggs in the soil. The adult female lays, on an average, approximately 360 eggs over a period of 24 days. The eggs hatch in a period of 3- 5 days from the month between May-September and the young grubs feed on the roots of cotton as well as that of other plants. The grubs complete their entire development within a period of 1-2 months. They pupate in the soil inside earthen cells, forming creamy-white colour pupae, which change into adults in approximately one week. The adults live for a time span of 8- 11 days in the summer and for 4-5 months in the winter. During the active period, the life-cycle is completed within a period of 6-8 weeks and the pest perhaps breeds 3-4 times in a year. *Dinocampus mylloceri Walker* (Braconidae) parasitizes the larvae of this insect. Both adults as well as grubs cause damage. The grubs feed underground on the roots of cotton seedlings and destroy them. One grub can destroy approximately 9 seedlings in around 40 days. The adults which feed on leaves, buds, flowers as well as young bolls cut prominent round holes. The pest can be suppressed by disturbing the soil up to a depth of 7.5 cm and destroying the eggs, grubs and pupae. Apart from this, spray 2.5 kg of carbaryl 50 WP in 375 litres of water per ha. Figure 3.4 is depicting the life cycle of Cotton Grey Weevil, Myllocerus.

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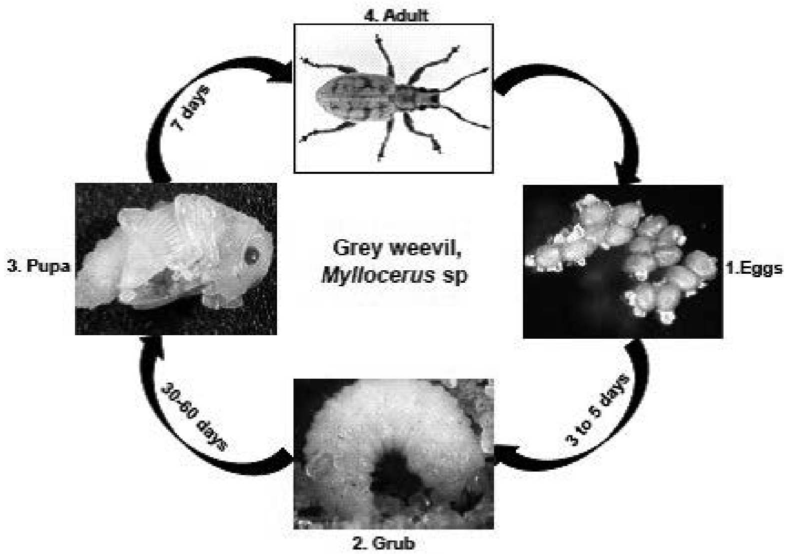

Fig. 3.4 *Life Cycle of Cotton Grey Weevil*

6. Cotton Stem Weevil, *Pempherulus affinis* (*Faust*) (Coleoptera: Curculionidae):

The grubs of cotton stem weevil feed on a variety of species of cotton in India, Myanmar, Thailand as well as the Philippines. In India, it is present in Tamil Nadu, Andhra Pradesh, Karnataka, Kerala, Bihar, Orissa, Rajasthan, Uttar Pradesh, Gujarat as well as Assam. The most favoured host of this insect is *Triumfetta rhomboidea* Jacq. The grubs feed on the soft tissues of cotton stems. Greyish-black weevils emerge from the stem killing the plants. The adult is a dirty brown or greyish-black coloured weevil, approximately 3 cm in length. The grub is somewhat curved, creamy white in colour, with a separate head. The weevils emerge out from the cotton sticks wherein they spend the entire summer season. After mating, the adult female creates a cavity in the hypocotyle region of the plant and lays an oval, globular, smooth, milky white egg. During the opposition period of 60-80 days, a female may lay up to 121 eggs visiting from one plant to plant. The eggs hatch within a period of 6-10 days and the grubs feed inside the soft stem tissue. They continue to feed inside till the development is completed in a period of around

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35-57 days. The pupation takes place inside the stem and this stage lasts from 25 to 30 days. Three generations are completed in a year between the months of October to April and the summer season is passed as an adult in the cotton sticks. This pest pose serious threat to Cambodia cotton seen in South India. As the grubs tunnel within the stem, that portion swells, and such symptoms are usually observed at the base of the plant. The younger plants when attacked succumb, on the contrary, the older plants may live, however, hurt in vigour. Under the influence of very strong winds, the affected plants may break at the swellings. The pest increases the plant mortality up to 25 per cent, particularly during the early stages of growth. Collection as well as destruction of the affected plants is suggested for effective controlling of this pest, and it is recommended to avoid growing of alternate or collateral host plants during the off season.

3.2.2 Pests of Sugarcane

1. *Pyrilla perpusilla*

It is commonly known as sugarcane plant hopper, is majorly found is Asian countries like Afghanistan, Bangladesh, Burma, Cambodia, India, Indonesia, Nepal, Pakistan, South China, Sri Lanka, Thailand, as well as Vietnam. *Pyrilla* is a major pest in Bihar, Delhi, Haryana, Punjab, Madhya Pradesh, Uttar Pradesh, Maharashtra, Gujrat, and Orissa. In the recent years, its incidence has increased in peninsular India. The original host of *P. perpusilla* is not known however it has been recorded feeding and reproducing on a broad range of species of Gramineae, Leguminae as well as that of Moraceae families.

Kingdom- Animalia

Phylum- Arthropoda

Class- Insecta

Order- Hemiptera

Family- Lophopidae

Genus- *Pyrilla*

Adult of *Pyrilla perpusilla* is a pale tawny-yellow colored, soft-bodied insect with head region conspicuously drawn to forward direction to form a snout. The wingspan of males is approximately 16 - 18 mm in length whereas that of females is around 19 - 21 mm in length.

Females possesses cretaceous threads known as anal pads, arranged as bundles on terminal segment. The fore wings are semi-opaque in nature, and are yellow-brownish in color. The fore wings of the pest are slightly covered with minute black spots. Both adults as well as nymphal forms of the pest are very active and suck sap from the leaves of sugarcane. On the smallest disturbance, they jump from leaf to leaf. Adult females lay eggs on the lower, shady and concealed side of the leaves near the midrib. Eggs are laid in clusters of around 30-40 in number in rows of 4-5. Eggs are covered by pale waxy material. Eggs are oval-shaped, pale whitish to bluish green in colour when laid and turn brown just before hatching. A female lays approximately 600 - 800 eggs in her lifetime.

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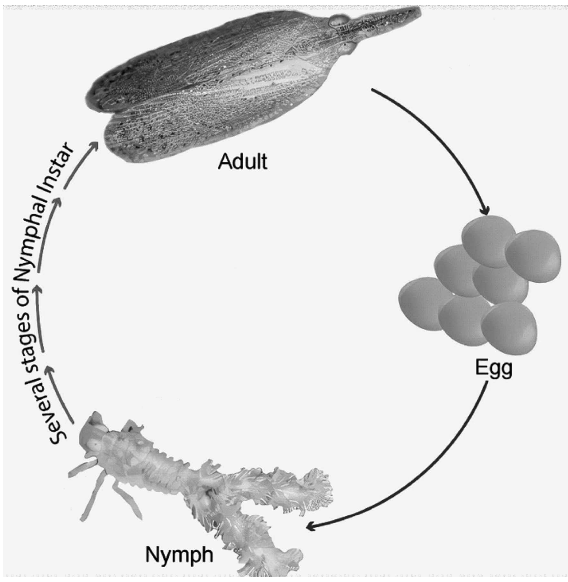

Fig. 3.5 *Life Cycle of* Pyrilla Perpusilla

Figure 3.5 is depicting the life cycle of *Pyrilla perpusilla.* It passes through five nymphal instar stages to reach the adult stage. The following table 3.1 gives the information about the features of each instar nymph:

Table 3.1 *Features of Instar Nymph*

	Body Size	**Body Color**	**Eyes**	**Duration**
I Instar Nymph	L-1.4 mm B-0.6 mm	Greenish white	Dark red	7 Days
II Instar Nymph	L-2.1 mm B-0.9 mm	Pale white to brown	White and translucent with black spot	5 Days
III Instar Nymph	L-2.7 mm B-1.2 mm	Pale brown	Grey green	5 Days
IV Instar Nymph	L-3.3 mm B-1.6 mm	Dark brown	Watery green	6 Days
V Instar Nymph	L-4.9 mm B-2.3 mm	Pale to dark brown	Water green	9 Days

First nymphal stage has whitish thorax having a thin transverse pale brown band on the posterior end. The last abdominal segment is greenish in colour with whitish threads. The second instar nymph has dark brown strips along the lateral margin. The third instar nymph has a thoracic region having one dark brown dorsal patch on either side. Abdominal segments are pale blue on dorsal side and pale yellow on ventral side. Abdominal segments of fourth instar nymph have a dark brown band on the dorsal surface and pale green ventral surface. Abdominal segments of fifth instar nymph have a dark brown transverse band on the dorsal surface and pale white ventral surface. Anal tufts are buff colored. The adults of *Pyrilla perpusilla* are whitish in colour, however, later on the body colour of the adult turns into straw color, eyes turn pale green in colour whereas head develops a snout with a black spot at the posterior side. The anterior area has several small black spots.

The adult female measures approximately 10 mm in length and 2.2 mm in breadth on the contrary male measures approximately 8 mm in length and 3.5 mm in breadth. Adult females are ready to mate within two days after the emergence from the fifth nymphal instar. Female lays eggs majorly during the day time. Leaves turn yellowish white and wither away due to heavy infestation of *Pyrilla perpusilla.*

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Heavy infestation leads to huge loss of the production due to poor growth of seed sets and complexities in milling cane from the infected plants. Sucking of sap from the leaves weakens the plant as well as reduces the sucrose contents by up to 50%. The hoppers release a sweet sticky fluid known as "honeydew" which promotes a quick growth of fungus known as *Capnodium* sps. Completely coverage of leaves by the sooty mold affects the process of photosynthesis.

Control Measures of *Pyrilla perpusilla*

- The Burning of trash helps in destroying both unhatched eggs as well as overwintering nymphs.
- During the pre-monsoon season, dusting the fields with 5-10% HCH at 20-30 kg/ha or methyl parathion (2%) at 12.5 kg/ha with a rotary duster can be useful.
- During *Pyrilla* epidemics aerial sprayings of the following insecticides must be done regularly:
  - Fenthion (560 ml/ha),
  - Malathion (500 ml/ha),
  - Phosphomidon (250-300 ml/ha)
  - Monocrotophos (1250 ml/ha)
  - Endosulphan (750 ml/ha)

3.2.3 Pests of Paddy

1. Yellow Stem Borer: *Scirpophaga incertulas*

Scirpophaga incertulas is one of the major pests of paddy. It is a very particular pest of paddy and has worldwide distribution. It is very serious in areas where more than one crop of paddy is considered in a year. These moths are medium-sized, 10-15 mm in length, having yellowish forewings, whitish hind wings, and black dot on each of the forewings as well as tuft of yellowish hairs on anal segments in female moth. Caterpillar are yellowish in colour, 20 mm in length with yellowish-brown head. Yellow stem bore is the one of the major pest among the other pests of paddy. Once the larva hatches out from the egg, it begins boring inside the stem of paddy plant. Due to continuous feeding by larva, the central shoot of the paddy is killed causing "dead heart". The attack in the later stage leads to yellowing of leaves as well as white ear-heads locally known as **'Palinj'**.

Approximately, 100-200 eggs are laid on the upper surface of leaves near the tips. The insect remains in the larval stage for a period of 4-5 weeks. The life cycle of insect comprises of 6 larval instars, before pupation larva, construct an emergence hole on the stem which is always situated above the water level in fields. Pupal period is approximately 8-10 days. The longevity of adults is 5-7 days. Life cycle is completed within a span of two months. 3 to 5 generations occur in a year. The pest hibernates in larval or pupal stage in the stubble during the winter season. Cold weather with high humidity and low temperature has been observed favorable for the multiplication of the pest. Figure 3.6 is depicting the life cycle of yellow stem borer.

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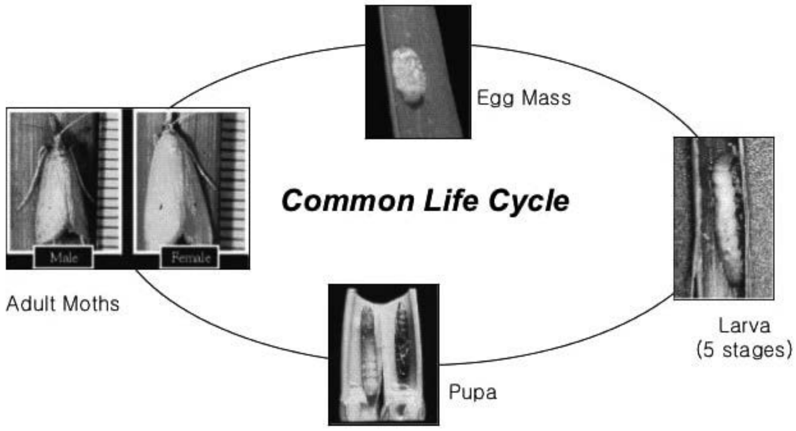

Fig. 3.6 *Life Cycle of Yellow Stem Borer*

2. Stripped Stem Borer (*Chilo partellus, S. Pyralidae* : Lepidoptera)

Stripped stem borer is also considered under the major pests of paddy.

Moths are medium sized, 10 mm in length, forewings are yellowish-grey in colour with small black spots present at apical portion, whereas hindwings are dirty white in colour. Caterpillars are dirty white in colour with brownish markings. This pest attacks rice, paddy, jowar, maize, sugarcane, some hill millets as well as wild grasses. Caterpillars initially feed on leaves and later on bore inside the stem producing dead hearts or empty ear-heads depending upon the stage of the crop. Approximately, 200 eggs are laid on leaves by female adult. The total time period of larval stage is around 15-26 days. Pupation occurs in stem. Pupal period is 3-5 days. The entire life cycle is completed within a period of 6-7 weeks. Pest hibernate as a larva in stubble in the off season. The pest is active from the month of July to November. In order to manage both yellow stem borer and stripped stem borer, following practices are adopted:

I. Cultural and Mechanical Measures

1. Avoid late transplanting of the crop.
2. Grow high yielding mid-late varieties like Ratna, EP-4-14, I.R.20, IET-3116, IET-3127, IET-9691 and IET-3093.
3. Remove all the affected tillers and destroy them.
4. Clipping of leaf tips at the time of transplanting in order to destroy the egg masses.
5. Plough the field immediately after harvest and destroy the stubbles.
6. Conservation of frogs in order to keep down the incidence of stem borer, army worm, crabs, etc.

II. Chemical Control

1. Chemical control involves application of phorate 10 G @ 10 kg or quinalphos 5 G @ 15 kg or carbofuran 3 G @ 16.5 kg/ha in the soil under saturated moisture conditions approximately fifteen days after sowing. If granular application is not possible due to inadequate soil moisture (sloppy or light type of soil) then spray with fenitrothion 0.08% or quinalphos 0.08% or phenthoate 0.08% when 1 moth or 1 egg mass/ sq.m. is noticed.

2. Dipping of Seeding Roots: Dip seedling roots for around 12 hrs. in the solution which is prepared by mixing chlorpyriphos 20 EC, 500 ml. in 500 liters of water (0.02% solution). For this treatment the bed should be prepared by spreading the plastic sheets and making ridges on all four sides for preparing the solution.
3. Field Application: When 5% dead hearts appear in the field or average 1 egg mass / sq.m., apply granules in the soil as given under nursery treatment. At the time of application, the field should have a saturated moisture condition or a maximum of 7-10 cm. of water level. Do not let in or drain out water for 4 days after application, or spray the crop with insecticides given under nursery treatment or spraying of Bt @ 1 kg/ha. when 5% affected tillers sq.m. or 1 eggs mass/ sq. m. or 1 moth/sq.m. is noticed.

III. Biological Control

Release of laboratory-based parasitoids, *Trichogramma japonicum* 4-5 times at weekly intervals @ 50,000/- parasitoids /ha on noticing stem borer moth activity.

3. Rice Gall Midge or Gall Fly (*Orseolia oryzae*)

Rice gall fly is one of the major pests of paddy. This pest is widely distributed throughout the India. This pest has been found to be endemic in Bhandara, Chandrapur as well as Ratnagiri districts of Maharashtra State. The loss in production in heavily infested crop may be to the extent of 50 per cent. Adult fly are small, reddish brown in colour, mosquito like having long slender legs, body length of 4-5 mm. Maggot are pinkish in colour having 2.5 – 3.00 mm in length.

The tiny maggot which emerges out from the eggs creeps down between the leaf sheaths till it reaches the apical point of the central shoot or tillers as the case may be. After this, it enters the tissues and then destroy the growing point. Due to continuous feeding normal growth of the plant stops and a small gall is produced. This gall slowly elongates and a long hollow silvery shoot emerges in place of normal stem bearing the ear-head. The affected plants encourage tillering however, by the time, flies may emerge in the consecutive generation and again attack the tillers and in case of severe infestation a very huge percentage of plants yield no grains at all. The infestation is highest in the tillering stage. The infested tillers do not bear ears.

Female lays approximately 100 eggs on leaves singly or in clusters. The incubation period of eggs is around 3-5 days. The total larval period is around 10 days. The pupation occurs in galls or within the silver shoot. The pupal period 3-5 days. The entire life cycle is completed within a span of 2-3 weeks and 5-8 generations occur in a year. The pest probably overwinters in the larval stage in stubbles.

Cloudy skies as well as drizzling rains are favourable to a fast build-up of pests. The suitable environmental conditions for the development of insects is 26 to 30°C temperature and 82 – 86 % humidity. Heavy rains as well as low humidity leads to high mortality.

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Management Practices:

(A) Cultural and Mechanical Measures:

1. Destroy all wild grasses as well as alternate hosts present in and around the rice fields in order to prevent the infestation of this pest.
2. Grow highly resistant varieties like IET 7918, IET 6080, IET 7008, Pratap, Kunti, Suraksha, Vikram as well as Phalguna.
3. Removal of affected tillers showing silver shoots as well as their destruction will keep the pest under check.

(B) Chemical Control:

1. First chemical treatment could be nursery treatment; Give nursery treatment as stated under rice stem borer, when 1 silver shoot/sq.m. is noticed.
2. Field Application: When 1 silver shoot or gall/sq.m. in an endemic area or 5% silver shoots/sq.m. in a non-endemic area, apply phorate 10G @ 10 kg or quinalphos 5G @ 15 kg in soil control the pest effectively.

Note: Granules should be applied carefully and should not be handled by persons having wounds on feet or hands.

4. Rice Jassids (Green Leaf Hoppers) (*Nephotettix nigropictus*)

In the recent years, this pest seems in endemic forms in few parts of Maharashtra. Host Plants includes Rice, wheat, barley and lemon grass. Apart from damages caused by direct feeding, they also acts as vectors of rice virus diseases and have almost the same overall economic significance as stem borers. Adult are greenish in colour, wedge-shaped, 4-5 mm in length, having black spot on each forewing. Nymphs are smaller, wingless as well as greenish in colour.

Both nymphs as well as the adult stages suck the cell sap from the leaves. Consequently, the leaves turn yellowish in colour and start drying from tip to downwards. A few species are known to be the vectors of virus diseases. The green leaf hoppers. *N. nigropictus* are reported to transmit 'rice transitory yellowing' as well as 'rice yellow dwarf'. Tungro virus disease is transmitted by *N. virescens* is the most serious.

Approximately, 25 eggs are laid per female within the leaf tissues. The incubation period of the eggs is around 4-5 days. The nymphal period varies between 10-15 days. Adult longevity is around 17-22 days in summer and 30-50 days in winter. The entire life cycle is completed in about 5 weeks. Six overlapping generations occur in a season and several in a year. Over wintering in the adult stage, through alternate host plants.

This pest remains highly active during the month of July-Sept. The abundance of the pest has been credited to environmental conditions like high temperature, low rainfall, as well as abundant sunshine. Usually, fields which receives huge amounts of nitrogenous fertilizers gets infested. The pest population generally decreases after the heavy rain. Incidence occur more frequently in ill drained fields. Spray with dimethoate 0.05% or fenitrothion 0.05% or monocrotophos 0.05% or malathion 0.1% or phenthoate 0.05% or dusting carbaryl 10 D @ 20 kg/ha when 1-2 jassids / sq. m. in nursery and 5-10 or more jassids/hill in the field.

Note: Dusting should be undertaken in the evening or early in the morning when there is no wind.

Figure 3.7 is depicting the life cycle of green leaf hopper.

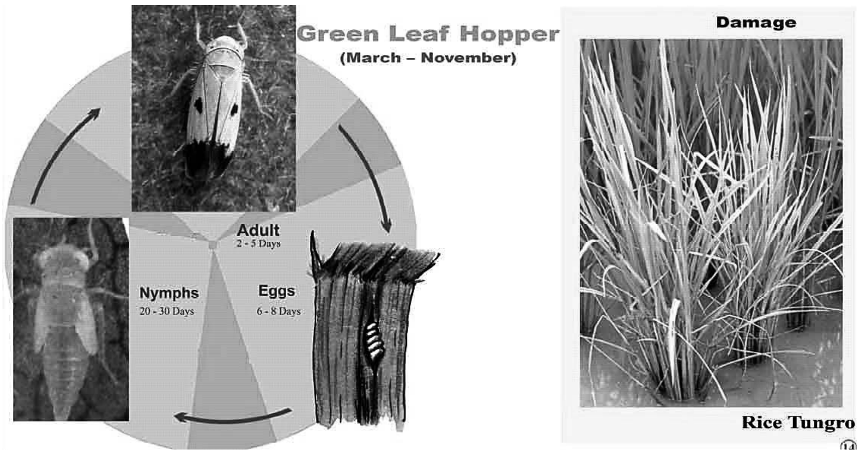

Fig. 3.7 *Life Cycle of Green Leaf Hopper.*

5. Brown Plant Hoppers (Pest of Paddy) (*Nilparvata lugens*)

It is one of the most destructive pest. This pest has become serious on high yielding varieties of paddy in several states. Nymphs as well as adults are brown to brownish black in colour, adults are approximately 4.5 mm in length. Two types of adults are noticed – 1. Brachypterous –in which the wings are not fully developed. 2. Macropterous – in which the Wings development is complete. Host Plants includes paddy, sugarcane as well as some grasses. Both nymphs as well as the adults suck the cell sap from stem and leaves. Consequently, the leaves become yellow in colour, gets dried up and the entire plant dies after a few days. They usually remain limited to the basal portion of a rice plant. When the population of the pest remains high, the crop dries up in patches and this stage is referred to as 'hopper burn'. They also transmit grassy stunt virus disease of paddy. Very high infestation causes lodging of the crop. Approximately, 300 – 350 eggs are laid per female in leaf tissues on either side of the midrib as well as on the leaf sheath. The incubation period of the eggs is around 6-12 days. Nymph-nymphal period is of 15 days. Adult- lives for 10-20 days in summer and 30-50 days in autumn. Several generations in a year.

It overwinters either as eggs or fifth in star nymphs through alternate host plants. High nitrogen application, high humidity as well as optimum temperatures increases the population quickly.

Management Practices includes: 1. Grow BPH resistant/tolerant varieties viz., IET-7575, IET-7568, IET-7943 and IET-8115. 2. Spray the crop with insecticides given under the leaf hopper when 5-10 hoppers/hill are noticed. However, make sure that the insecticide reaches lower portion of the plant.

3.2.4 Pests of Stored Food Grains

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Insect pests increase the costs of grain both directly via the expense of control on the farm, as well as indirectly via the costs incurred by grain handling authorities in controlling weevils in bulk storages. Primary grain insects are those insects which have the ability to attack whole, unbroken grains, whereas secondary grain pests attack only damaged grain, dust or milled products. List of stored grain insect pests of India is shown in table 3.2.

Table 3.2 *List of Stord Grain Insect Pests of India*

Common name	Pest	Host
Primary pests		
Rice weevil	*Sitophilus oryzae, Sitophilus zeamais, Sitophilus granarius*	Rice, wheat, sorghum, barley, maize
Khapra beetle	*Trogoderma granarium*	Cereals, groundnut and pulses
Angoumois grain moth	*Rhyzopertha dominica*	Paddy, maize and wheat
Grain moth	*Sitotroga cerealella*	Rice, wheat and maize
Rice moth	*Corcyra cephalonica*	
Lesser grain borer	*R. dominica*	
Pulse beetle	*Callosobruchus chinensis, Callosobruchus maculatus*	Pulses, bean and grain
Tamarind/groundnut bruchid	*Caryedon serratus*	Groundnut, tamarind and other legumes
Cigarette beetle	*Lasioderma serricorne*	Wheat flour, cereal bran, groundnuts, cocoa beans, spices, turmeric, chillies, ginger, stored tobacco, cigarettes
Drug store beetle	*Stegobium paniceum*	Turmeric, coriander, ginger, dry vegetable and animal matter
Sweet potato weevil	*Cylas formicarius*	Sweet potato
Potato tuber moth	*Phthorimaea operculella*	Potato
Secondary pests		
Red flour beetle	*Tribolium castaneum, Tribolium confusum*	Broken grains, damaged grains, milled products, machinery
Long-headed flour beetle	*Latheticus oryzae*	
Saw toothed grain beetle	*Cryptolestus minutas, Laemophloeus pusillus*	Dry fruits, maize, cereals and oilseeds
Red rust grain beetle	*Cryptolestes ferrugineus*	
Flat grain beetle	*Cryptolestes pusillus*	

Source: Ahmad (1983).

(Reference: - Integrated Pest Management in Stored Grains by Uma Shankar and Dharam P. Abrol).

1. Lesser Grain Borer (*Rhyzopertha dominica*)

Rhyzopertha dominica is one of the most serious pest of stored grain. It is found mainly in cereal stores, and food and animal feed processing facilities. Adults and larvae of *R. dominica* feed primarily on stored cereal seed including wheat, maize, rice, oats, barley, sorghum and millet. They are also found on a wide variety of foodstuffs including beans, dried chillies, turmeric, coriander, ginger, cassava chips, biscuits and wheat flour. This beetle is around 3mm in size, dark brown in colour having a cylindrical shape. The head is hidden by the thorax when viewed from above. Female lays approximately 200- 500 eggs during its lifetime scattered loosely through the grain. The eggs hatch to produce curved white larvae having brown heads and three pairs of legs. The larvae burrow into slightly damaged

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grains and eat out the starchy interior. After pupation, the adults emerge from the grain, leaving large irregular exit holes. The completion of life cycle depends on the temperature. Adults may live up to four months. The fastest rate of development occurs at 34°C; at this temperature the egg takes 2 days, the larvae 17 days, and the pupae 3 days to complete development. *R. dominica* is unable to complete development between 38 and 40°C. The lowest temperature at which *R. dominica* can complete development is 20°C; at this temperature, the development from egg to adult takes 90 days. The adult lesser grain borers chews grain voraciously causing damage which may facilitate infestation by a secondary pest. It is a strong flyer and may rapidly migrate from infested grain to begin new infestations elsewhere. Figure 3.8 is depicting the life cycle of lesser grain borer.

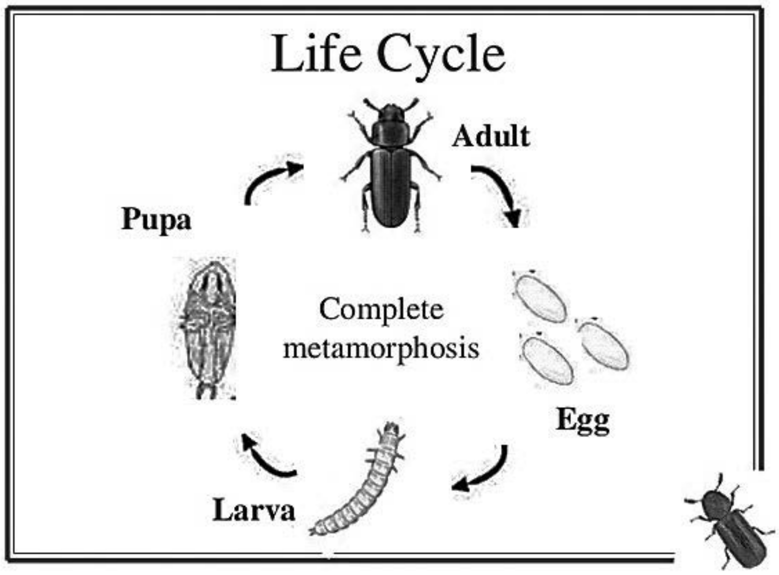

Fig. 3.8 *Life Cycle of Lesser Grain Borer*

2. Rice Weevil (*Sitophilus oryzae*)

The rice weevil is one of the most serious stored grain pests worldwide. *Sitophilus oryzae* is small, approximately 1/10 inch (2 to 3 mm) and firm in appearance. It looks similar to the granary weevil. However, unlike the granary weevil, the rice weevil is winged and may occasionally fly. The color of the rice weevil varies from reddish-brown to black in color having four light yellow or reddish spots on the corners of the elytra (the hard protective forewings). The snout is approximately 1mm in length. The head with snout is as long as the prothorax or the elytra region. The prothorax- it refers to the body region present behind the head is strongly pitted and the elytra comprises of rows of pits within longitudinal grooves. The larva is legless and stays inside the hollowed grain kernel. The larvae have a cream-colored body with dark head capsule.

The adult female rice weevil lays an average of 450 eggs singly in holes chewed in cereal grains. The full life cycle may take only 26 to 32 days during hot summer months, but requires a much longer period during cooler weather. The eggs hatch in about 3 days. Each egg hatches into a white, legless larva, which eats the grain from the inside. The larvae feed inside the grain kernel for an average

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of 18 days. The larva pupates within the grain and the adult then chews its way out. The pupa is naked and the pupal stage lasts an average of 6 days. The new adult will remain in the seed for 3 to 4 days while it hardens and matures. The exit holes are characteristic signs of weevil damage. The rice weevil has four orange-brown areas on the wing cases, and is about 3mm long with a characteristic rostrum (snout) protruding from its head. It has biting mouth parts at the front of the rostrum and two club-like antennae. Figure 3.9 is depicting the life stages of rice weevil.

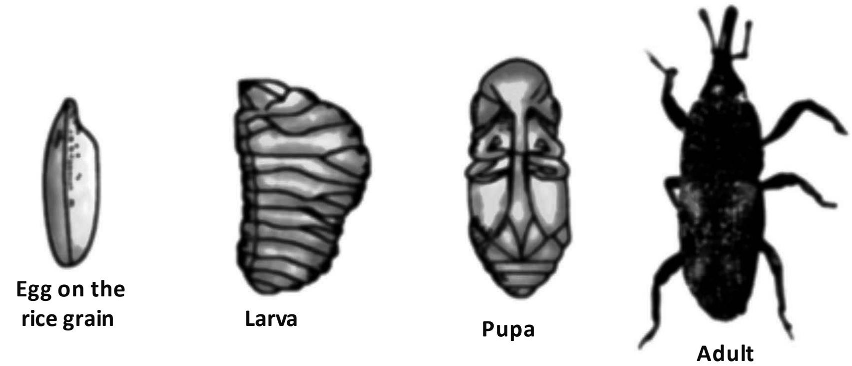

Fig. 3.9 *Life Stages of Rice Weevil*

3. Angoumois Grain Moth (*Sitotroga cerealella*)

The angoumois moth is yellow-brown in colour having darker markings on the body. The wingspan is approximately 12-20mm. Adult females lay around 250 eggs on or near the surface of stored grain. The eggs hatch into a caterpillar which bores into grain kernels remaining inside until maturation. Adult then eats its way out of the grain, leaving distinctive exit pin holes on the grain surface. However, no surface web is formed as seen in other moth pest. The life cycle is usually completed in five weeks. Infestation by *Sitotroga cerealella* causes unpleasant smell as well as taste to the cereal. Figure 3.10 is depicting the life cycle of *Sitotroga cerealell.*

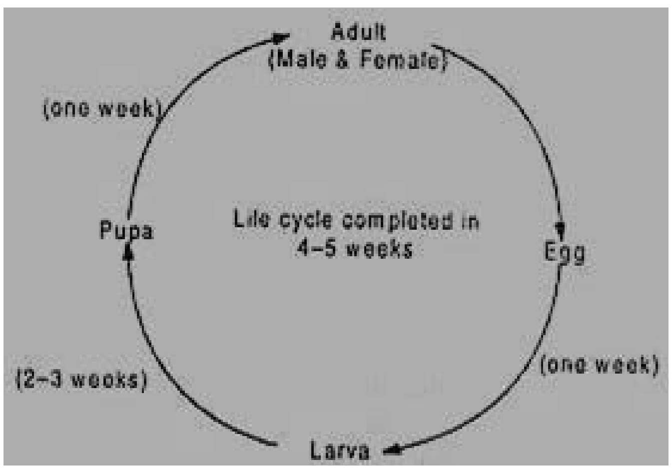

Fig. 3.10 *Life Cycle of Sitotroga cerealell*

4. Herbst (*Tribolium castaneum*)

Tribolium castaneum is worldwide in distribution, but more common in warmer regions. Host plants includes: Grain products, dried foods, pet foods and dried flowers. The adults are flat, reddish-brown in color, about 3-4 mm in length, thorax is

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slightly darker as compared to elytra. Last three antennal segments of pest are larger than all others, almost square. Larvae are initially whitish in color, however, they slowly become brown in colour with a length up to 5 mm, and terminal abdominal segment bears a pair of dark, upturned projections. The adult of *Tribolium castaneum* is long-lived, occasionally living more than three years. The females mate numerous times, and lay approximately 300-600 eggs. The eggs are covered with a sticky material to which flour particles adhere. The newly hatched larvae can feed on any available food for approximately 3-4 weeks and pupate. The life cycle of the insect pest completes in 7 to 12 Weeks, depending on the temperature conditions; however, the optimum temperature is 35°C with 60-80% relative humidity. These beetles can disperse by flight

A major pest of stored products, particularly in warmer climates. It infests mostly seeds, kernels as well as other products, generally, those that had already been wounded by other pests or damaged during harvest and storage. The affected product becomes contaminated with faeces, and the increased humidity promotes molding. Economic losses comprise of reduced weight of the grain and overall decrease in product quality, problems in baking, reduced market of the infected products and an associated hostile smell. Pest presence may also cause allergic responses.

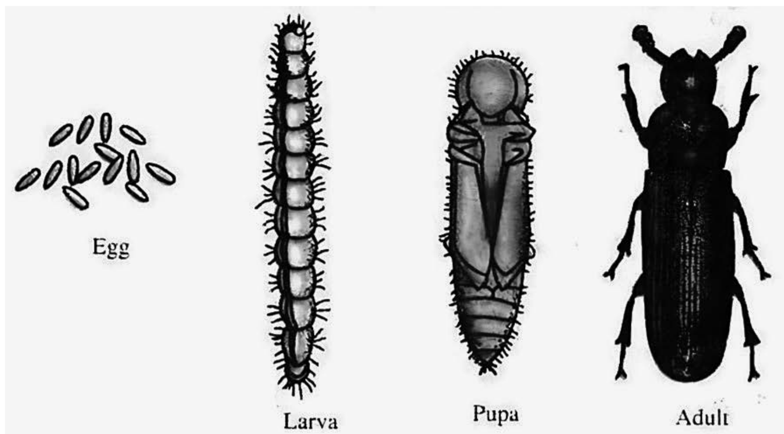

Fig. 3.11 *Different Stages of Tribolium castaneum*

3.2.5 Pests of Citrus and Mango

1. Citrus Aphid

Eggs are not produced by this species. Females directly give birth to living young. The life cycle includes four nymphal stages. The first stage is around 1/36 inch in length and the fourth is about 1/17 inch. They lack wings and are brownish in color. Newly born nymphs are found grouped together as mothers do not move about while giving birth. Female adults are oval in shape, shiny black, brownish-black or reddish brown in color, either with or without wings, measuring approximately 1/25 to 1/12 inch in body length and having short black-and-white banded antennae. Winged individuals tend to have darker abdomens that will be slightly thinner. The incidence of winged individuals is dependent on the population density as well as the leaf age. Citrus aphid is the only aphid having an audible stridulation or high piercing sound which is caused by the aphid rubbing two parts

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of it body together much like crickets. Large colonies will produce this scrapping sound when they are disturbed. About thirty generations succeed each other and overlap throughout the year. The favourable conditions for the development of citrus aphid are: Optimum temperature for this aphid is 20 to 25°C as well as lower winter temperatures and especially summer heat (above 30°C) slow down development. Citrus aphid feeds vigorously on tender foliage as well as flowers. It transmits Citrus Tristeza Virus disease. Nymphs as well as the adult stages suck the sap of leaves which leads to wilting and flower dropping. Infested leaves become cup shaped and crinkled. Growth of the plants is hindered. Figure 3.12 is depicting the life cycle of Citrus aphids**.**

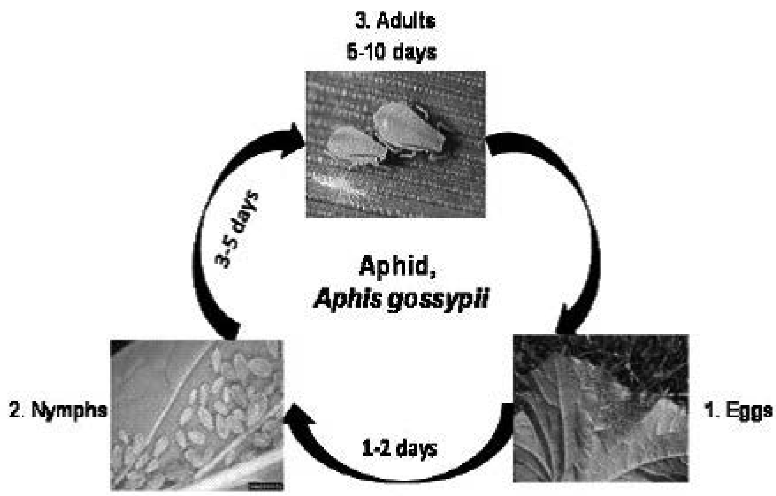

Fig. 3.12 *Life Cycle of Citrus Aphids*

2. Citrus/Lemon-Butterfly

Eggs are yellowish white in colour, round in shape, smooth eggs are laid singly on tender leaves as well as shoots by *P. demoleus*. Egg hatches in approximately 3 – 8 days. Freshly hatched caterpillars are dark brown in colour and soon develop asymmetrical white markings on their body resembling the bird's drop. The caterpillars feed insatiably on tender leaves right up to the mid ribs and defoliate the entire seedlings or the tree leaving behind only the midribs. The caterpillars hold on to branches, transforming into pupae. They continue to be in the pupal form for 2–3 weeks before emerging as adults. *P. demoleus* is a big beautiful butterfly having yellow to black markings on all the four wings, having wing expanse of approximately 50-60 mm. The hind wings of Citrus/Lemon butterfly have a brick red oval patch situated near the anal margin and there is no tail like extension behind though common in *Papilionidae*. *P. polytesmales* are black in colour and females vary in form. *P. helenushas* black wings with three white distal spots.

The density of the larvae remains high during the month of October to December. Month between July to December are the most favourable period of its activity in general. Citrus butterfly was able to survive during the winter even though temperatures dropped below 0°C. Caterpillars of the citrus butterfly selects light green tender leaves for feeding. They feed voraciously leaving only the mid-ribs. In case of heavy infestation, the entire tree gets defoliated. Figure 3.13 is depicting the life cycle of Citrus butterfly.

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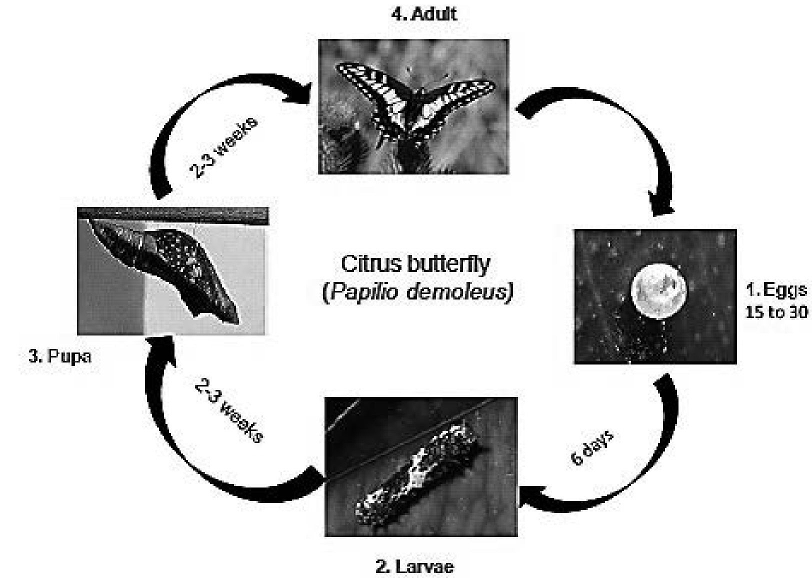

Fig. 3.13 *Life Cycle of Citrus Butterfly*

3. Citrus Psylla

Eggs are approximately 0.2-0.3 mm in length, pear shaped orange to yellow, primarily turn darker as they are ready to hatch. The nymphs are yellow, orange or brown in colour with flattened bodies. Nymphs are very difficult to spot as they're only 1/100 to 1/14 inch long. The nymphs also secrete a sticky substance which is known as honeydew that attracts sooty mold. The Asian citrus psylla is a tiny, mottled-brown, winged insect that damages curry leaf plants when it sucks sap out of young leaves. This psyllid grows to be between 1/16 and 1/8 inch long with red eyes and short antennae. Summer as well as rainy seasons are the most favourable season for its growth. Asian citrus psyllids are mottled brown insects that feed directly on the leaf of the curry tree. Heavy feeding damages both leaves as well as stems, and can also introduce bacteria to the tree. Psyllids, like other Homoptera, have piercing sucking mouthparts which are used for feeding on plants. Feeding by psyllid adults as well as nymphs causes newly forming leaves to twist and curl similar to feeding damage from the green aphid. Psyllid feeding also leads to reduction of shoot length giving a witches' broom effect. If heavy feeding occurs early on the developing flush, the new flush will fail to develop or abort. In addition to direct feeding damage, honeydew inside the white waxy secretions produced by the nymphs promotes the growth of sooty mold which can reduce effective leaf area for photosynthesis. Figure 3.14 is depicting the life stages of Citrus Psylla.

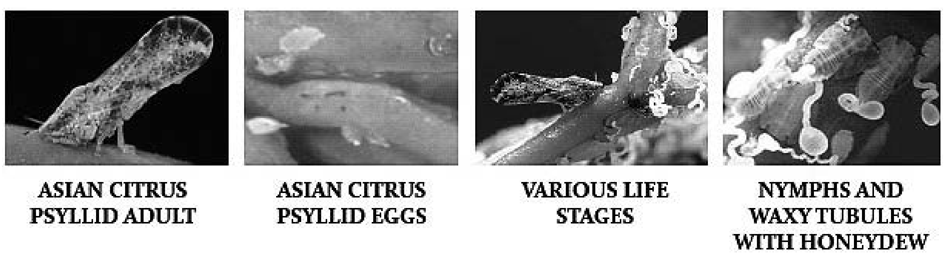

Fig. 3.14 *Life Stages of Citrus Psylla*

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4. Citrus Leaf Miner

Eggs are minute (approximately 1.0 mm in length and 0.2 mm in width), greyish or yellowish white in colour and slightly translucent. Eggs are laid inside the leaf tissue, just below the leaf surface. In few instances, eggs are laid below the epidermis of fruits/pods (for instance: - peas). Eggs hatch in approximately a period of three days.

Larvae are small yellow maggots (which are approximately 2 to 3 mm in length when fully-grown). Larvae are found to be feeding inside the leaf tissue, leaving long, slender, winding, white tunnels (mines) through the leaf. The insect pass through three larval stages. After a period of five to seven days, the maggots leave the mines and then pupate either on the leaf surface or - most commonly - in the soil. In few instances, maggots pupate within the mines. Pupae are very small, about 2 mm in length and 0.5 mm in width, pupae are oval, slightly flattened ventrally with variable colour varying from pale yellow-orange to golden-brown in colour. They have a pair of cone-like appendages which is situated at the posterior end of the body. Adults emerge 4 to 5 days after pupation. Adult insects are small, approximately 2 mm in length. They are greyish to black in colour with yellow markings on the body. Adult Female are slightly larger as compared to males. The life cycle of the insect varies with host as well as environmental conditions like temperature. The average life cycle is around 21 days in warm conditions, however, can be as short as 15 days. Thus, populations can increase quickly. Citrus leaf miner develops best at temperatures between 70º to 85ºF and greater than 60% relative humidity, however, will readily adapt to most California conditions. Citrus leaf miner larvae feed by creating shallow tunnels, which are known as mines, in young leaves. This pest is majorly found on citrus (oranges, mandarins, lemons, limes, grapefruit and other varieties) as well as closely related plants (kumquat and calamondin). The larvae mine the lower or upper surface of the leaves causing them to curl and look distorted. Mature citrus trees (more than 4 years old) usually bear leaf damage without any effect on tree growth or fruit yield. Citrus leaf miner is expected to cause damage in nurseries as well as new plantings as the growth of young trees is retarded by leaf miner infestations. Though, even when infestations of citrus leaf miner are heavy on young trees, trees are unlikely to die.

5. Mealy Bug (Pest of Citrus)

Eggs of the mealy bugs are deposited as white cottony masses known as ovisacs on trunk as well as stems of citrus plants, giving the appearance of cotton spread on plants. The glossy, light yellow eggs are oval and around 0.3 mm in length. A female can lay approximately 300 to 600 eggs in its life period, which are deposited in groups of 5 to 20. Based on the season, hatching of eggs may occur after a period of 6 - 10 days or several weeks. Females lays approximately 30 eggs per day. Nymphal stages emerge from the ovisacs and characteristically settle along midribs and veins on the underside of leaves, young twigs, as well as fruit buttons. Wax as well as honeydew secreted by crawlers are visible indicators of infestations by mealy bugs. First instar nymphs are known as crawlers. The nymphs take around 6 to 10 weeks to reach maturity. The nymphs are yellow in colour, oval-shaped with red eyes, and covered with white waxy particles The female nymphs look like the adult female in physical appearance, while male nymphs are more elongated. Female nymphs have four instars. Males differ greatly;

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they have three instars and a pre-pupal stage. The size of the adult varies from 3 mm (females) to 4.5 mm (males) in length. The females are wingless, white to light brown in color, with brown legs and antennae. The body of adult females is coated with white wax and bears a typical faint gray stripe along their dorsal side. Short waxy filaments can be observed around the margins of their oval body with a slightly longer pair of filaments present at the rear end of their body. The adults' females of mealy bugs are wingless and, hence must be transported to subsequent host plants, even though, they are able to crawl for short distances. The immature stages can be blown by wind. Females can live for up to a period of 29 days based on the host plant. Males are similar in color to females and have two long backward-projecting white wax threads. Citrus mealy bug is an infrequent pest of citrus, occurring mainly in older, well-shaded groves planted on heavy soils. This pest feed on the roots, bark, foliage, as well as fruit. The citrus mealy bug injects toxic saliva while extracting plant sap leading to defoliation, fruit discoloration, fruit splitting, as well as fruit drop. Mealy bugs generally gather in huge numbers, leading to premature leaf drop and twig dieback when they feed. Like psyllids, they secrete honeydew, which attracts black sooty mold. Figure 3.15 is depicting the life cycle of mealy bug.

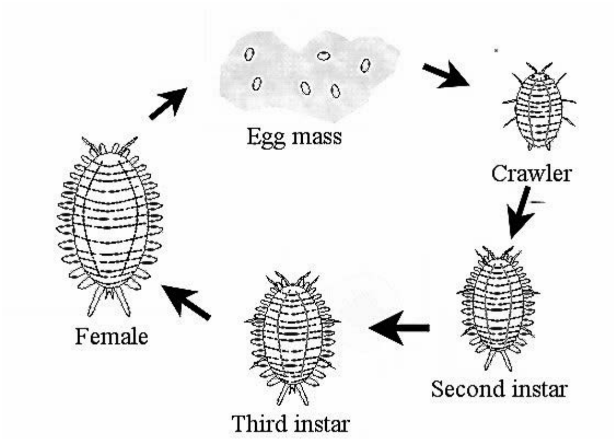

Fig. 3.15 *Life Cycle of Mealy Bug*

6. Fruit Sucking Moth (Pest of Citrus)

Eggs may be laid singly, or in egg masses comprising 50-750 eggs. Eggs are placed on the underside of young leaves, or on any part of the host. Sometimes eggs may be placed on inappropriate hosts, especially when the population density is high. Larval stages undergo four molts and five instars are produced. The larvae develop in a period of 21 days. Larvae can be seen feeding anytime on the underside or edges of leaves, however, typically feed between 5 PM and 10 AM. Whenever, the young larvae sense danger, they tend to respond by dropping to the ground, on the contrary, older larvae may show a typical aggressive posture and swaying motion. Pupation occurs approximately after 12.5-17.8 days within a pupal cocoon that may remain in the tree or drop to the ground after drying. The adult stage of fruit sucking moth is large and healthy. The eyes of this moth are large. The area which is present behind the head of the moth, the thorax, is pale to purple-brownish in colour and the abdomen is pale brownish in colour at the base brightening to yellow-orange

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at the tip. The forewings look like a leaf by being olive to purple-brown in colour and may have white and green colored flecks (the colored flecks are more common on females). This leaf-like physical appearance of the forewings makes this moth difficult to see when it is at rest, particularly, due to the bright hind wings are not visible. The outer edges of the female's forewings are scalloped or toothed where those of the males are uniform curved. The hind wings are bright orange in colour, have a black comma-shaped mark and are fringed by a black border with white dots. Fruit sucking moth is a serious pest of maturing mandarin fruits. The adults puncture the ripening fruits. The damaged fruits drop prematurely due to fungal infection as well as bacterial infections introduced via punctures leading to substantial fruit loss.

7. Citrus blackfly (*Aleurocanthus woglumi*)

Aleurocanthus woglumi, a species of whitefly originated in Asia, is referred to as citrus black fly because of its slate blue colour. Originated in Asia it was discovered in Cuba in 1916, Mexico in 1935 (Smith *et al.* 1964) and was detected in Key West, Florida in 1934. It was eradicated from Key West in 1937 (Newell *et al.,* 1939). Rediscovered in Ft. Lauderdale, Florida in 1976 (Dowell *et al.* 1981). At present, it is widely spread over central and south Florida from Cross Creek to Key West.

The eggs laid on spiral pattern on the abaxial side of leaves, hatch within 7-10 days. The brown coloured, elongate-oval first instar lasts 7-16 days and on average is 0.30 mm long x 0.15 mm wide. The second instar is covered with numerous spines and on average measures 0.40 mm long x 0.20. It lasts for 7-30 days. The body color of the third instar is shiny black, it lasts for 6-20 days, and on average is 0.87 mm long x 0.74 mm wide. The ovate shiny black colour pupal case or fourth instar lasts for 16-50 days. The life cycle from egg to adult varies from 45 to 133 days depending on the temperature (Dietz and Zetek 1920). At emergence the head is pale yellow, legs are whitish, and eyes are reddish brown. Within 24 hours after emergence the insect is covered with a fine wax powder which gives it a slate-blue appearance (Dietz and Zetek 1920). Citrus blackfly infests over 300 host plants, including species of citrus, mango, avocado, coffee, pear, plum, guava and ash but citrus is the most suitable for large population development. It damages citrus by sucking nutrients from foliage which weakens the plants. Citrus blackflies excrete honeydew on which sooty molds develop. Sooty molds coat citrus leaves, causing them to appear black. Sooty molds can severely impair leaf respiration and photosynthesis. Two parasitic wasps *Encarsia opulenta Silvestri* and *Amitus hesperidum Silvestri* (Hart *et al.* 1978) are the natural enemies of the citrus black fly. A. hesperidum lays eggs on all the larval stages of the black fly.it is most effective in areas which are heavily infested with fly under low temperature and high humidity conditions. However, the major disadvantage of this fly is its poor searching abilities and short life span. Encarsia opulenta has better searching abilities than Amitus hesperidum but has a lower rate of reproduction. Mated females lay eggs on any larval stage of the black fly population. Eggs are laid in a spiral pattern on the underside of the leaf. Adult female lays approximately two to three egg-spirals during her 10-to-14-day life span. Eggs hatch within a period of seven to ten days. The first instar is elongate-oval in shape, averaging 0.30 mm in length and 0.15 mm in width, brownish

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in colour, with two glassy filaments curving over the body. The first instar lasts seven to sixteen days. The second instar is more ovate as well as convex as compared to the first instar, averaging 0.40 mm in length and 0.20 mm in width, and is dark brown in colour with numerous spines covering the body. The second instar lasts seven to thirty days. The third instar is more convex and much longer when compared to the second, averaging 0.87 mm in length x 0.74 mm in width. The body is shiny black in colour with spines stouter and more numerous as compared to those seen in the second instar. The third instar lasts for six to twenty days. The fourth instar, or so-called pupa case, is oval in shape and shiny black with a marginal fringe of white wax. The sex is readily distinguishable. Females average 1.24 mm in length x 0.71 mm in width; males are 0.99 mm in length x 0.61 mm in width. The pupal stage lasts for 16 to 50 days. The adult of the citrus blackfly emerges out from a T-shaped split appearing in the anterior end of the pupal case. At emergence, the head is pale yellow in colour, legs are whitish in colour, and eyes are reddish-brown in colour. Within a period of 24 hours after emergence, the insect is covered with a fine wax powder which gives it a slate blue appearance. The development with high density citrus blackfly populations, especially during cool temperature and high humidity seasons. Citrus black fly is an endemic pest. The pest attacks the crop during all the three flushing periods namely, Ambia (months between Jan- Feb), Mrig (months between June - July) and Hasta (months between Oct - Nov) and completes three generations in a year. Both nymphs as well as the adults suck cell sap and secrete huge amount of honeydew on which sooty mould grows wildly that ultimately leads to fungal manifestation *(Capnodium sp.)* locally known as 'Kolshi', covering entire plant due to which the process of photosynthesis is affected. Plants are devitalized due to extreme desapping and in majority of the cases fruit bearing capacity of the tree is also affected. Fruits are rendered insipid in taste and blackened due to black sooty mould. These fruits get low very low price in the market.

Pests of Mango

1. Mango Hopper

Adult females lay more eggs and nymphs also develop faster during both the flowering as well as the fruiting period. Eggs hatch within a period of two to three days and nymphs develop between 12 to 20 days. The nymphs are greenish in colour with black or brown markings, cannot fly and move rapidly on the plant. Adult mango leafhoppers are golden-brown or dark brown in colour, wedge-shaped insects are approximately 4-5 mm in length which look somewhat like a small cicada. When disturbed, the adults of mango hopper jump off the plant with a clicking sound, fly a short distance and then quickly resettle on the plant.

The wedge shaped nymphs as well as the adults of these insects puncture and suck sap of tender parts, reducing the strength of plants and especially destroying the inflorescence and causing fruit drop. Heavy puncturing and nonstop draining of sap leads to curling as well as drying of infested tissue. These pests also damage the crop by excreting a sweet sticky substance which facilitates the development of sooty mould. Natural enemies of mango hopper are as follows:

- **Parasitoids:** *Polynema spp*., *Gonatocerus sp*, *Tetrastichus sp*
- **Predators:** *Mallada boninensis*, *Plexippus paykullii*

2. Mango Mealy Bug

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Adult females lay their eggs directly on the host plant in a fluted ovisac that remains attached to the body of the adult female. Inseminated eggs produce hermaphrodites as well as un inseminated eggs are produced by males. The first instar nymphs are also known as crawlers, which are mobile. Mango mealy bug settle down on the plants, begin sucking the sap and form the colonies. Adult females actually are hermaphrodites that frequently inseminate themselves. Adult males' mate with females, but it is not clear if their sperm are used for reproduction.

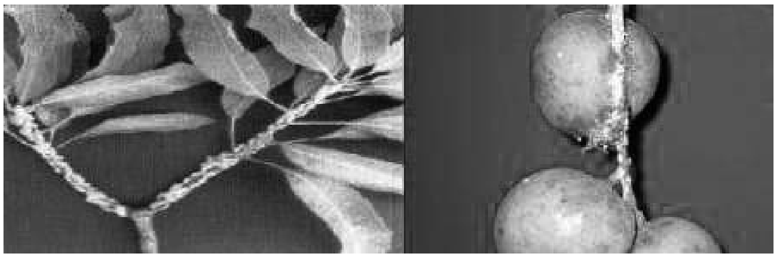

Fig. 3.16 *Damage Caused By Mango Mealy Bug*

Figure 3.16 is depicting the damage caused by mango mealy bug. The adult mango mealy bugs are covered with whitish powder and colonize between bark of tree trunk, young shoots and panicles. The nymphs climb on the trees and settle down on inflorescence leading to flower drop, affecting fruit set. Mango mealy bugs excrete honey dew, a sticky substance, which enables development of sooty mould.

3. Fruit Fly (Pest of Mango)

Adult female flies insert their eggs under the skin of fruit in clusters of 10 to 50 approximately 1/25 to 1/8 inch below the fruit surface. The eggs measure around1/ 25 by 1/250 inch and are white in colour, elongated, and elliptical in shape. They hatch in 1-1/2 days. The white colored maggot is legless, and appears like an elongated cone. The mouth is situated at the pointed end of the body. There are three larval stages, or instars. The third instar is approximately 2/5 inch long. The entire maggot stage lasts for 11-15 days. When the insect get mature, maggot drop to the ground and pupate in the soil. The puparium is yellowish-brown in colour and seed-like. Adults emerge in approximately ten days. Usually, the abdomen of adults bears two horizontal black stripes as well as a longitudinal median stripe which extends from the base of the third segment to the apex of the abdomen. These horizontal as well as longitudinal markings may form a "T" shaped pattern, however, the pattern differs substantially.. Adult females start to lay eggs approximately eight days after the emergence from the puparium. Under suitable conditions, a female can lay approximately 3,000 eggs during her lifetime, however, under field conditions around 1,200 to 1,500 eggs per female is considered to be the usual production. Ripe fruit are favored for egg laying, however, immature ones may be also attacked.

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Fig. 3.17 Damage Caused By Fruit Fly.

Figure 3.17 is depicting the damage caused by fruit fly. The female punctures outer wall of the mature fruits with the aid of its pointed ovipositor and then insert its eggs in small clusters inside mesocarp of mature fruits. On hatching, the maggots feed on fruit pulp and the infested fruits begin rotting due to further secondary infection. The natural enemies of the fruit fly are as follows:

- **Parasitoids:** *Fopius arisanus, Diachasmi morphakraussi*

4. Inflorescence Midge (Pest of Mango)

Eggs are laid singly on floral parts like tender inflorescence axis newly set fruit or tender leaves encircling the inflorescence. The eggs hatch within a period of 2-3 days. The minute maggots penetrate the tender parts where the eggs have been laid and begin feeding on them. The mature larvae drop down into the soil for pupation. The larval period last between 7-10 days, while the pupal period lasts between 5-7 days. Pupae are yellowish-brown in colour and approximately 1-2 mm in length, with male pupae generally smaller than females. Adults of Inflorescence midge are small midges with a wing length of 1.0-1.5 mm. Eye facets are circular, but further apart laterally than in other genera and the tarsal claws are toothed, which is unusual in Cecidomyiini. The ovipositor is protrusible however relatively short and the terminal cerci are fused to form a single lobe. The male gonocoxites are elongated and, unlike those of other Cecidomyiini, have a short mesobasal lobe.

The larvae tunnel the axis of inflorescence and destroy it entirely. Damage caused by E. indicacauses bending as well as drying of the inflorescences. Second attacks begin at fruit setting as young maggots bore into these tender fruits which slowly turn yellowish in colour and ultimately drops off. Third attack is on tender new leaves encircling inflorescence. The most damaging one is first attack in which the entire inflorescence is destroyed. The inflorescence shows stunted growth and its axis bends, at the entrance point of larva

Natural enemies of Inflorescence midge are as follows**:**

- **Parasitoids:** *Tetrastichus sp.*, *Platygaster sp.*, *Systasis dasyneurae*, *Aprostocetus sp*.

5. Stem Borer (Pest of Mango)

The eggs of stem borer are brownish-white in colour, cylindrical in shape, and 6 x 2 mm in size, with narrowly rounded ends. They are usually placed into an incision, which is approximately 25 mm in length, cut in the bark by the mandibles. The newly hatched first-instar larvae are approximately 10 mm in length. Fully grown larvae might reach up to 100 mm in length, however, most commonly they reach approximately 60-80 mm in length. The grub is subcylindrical, dorsoventrally flattened, and yellowish-white in colour, with the head dark brown and sclerotized, without obvious legs. The larva is described in detail by Duffy (1968) who also provided a key to separate out all known Oriental cerambycid larvae. Pupa is strong, approximately 80 mm in length, having few short, reddish setae on labrum and bases of mandibles as well as that of antennae. Sides of prothorax bears strong tubercle. Basal four abdominal segments with reddish hairs forming transverse interrupted band dorsally, segments five to seven with sparse setae. Apical segment ending with a spine on a strong subvertical acute prominence. Typical adults of cerambycid beetles, recognized by the long antennae reaching to at least the end of the body and the tarsi, the same on all legs, with seemingly four segments excluding the claws, however, with the third segment strongly bilobed and almost concealing the very small fourth segment at the base of the true fifth, claw-bearing segments. The Grub tunnels in the sapwood on the trunk as well as that of branches. Grub bore into the sap wood leading to irregular tunnels. Grubs feeds on the vascular tissues. Interruption of nutrient as well as that of water transport causes huge impact on the tissue. Drying of terminal shoot occurs in early stage. Frass comes out from different points and at times sap oozes out of the holes. Heavy infestations leads to wilting of branches or that of entire tree. Figure 3.18 is depicting the mango stem borer.

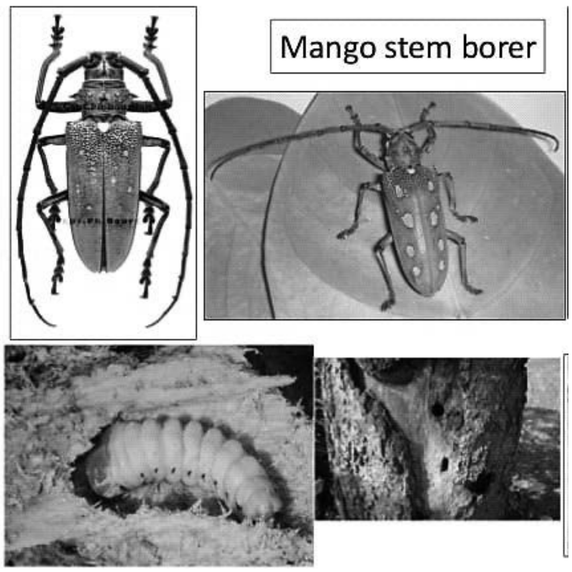

Fig. 3.18 *Mango Stem Borer*

3.2.6 Household Insect Pests

1. Ants

Small red ants: *Monomorium destructor; M. criniceps; M. gracillinum; M. indicum*

Large black ants: *Camponotus compressus*

Red odoriferous ants: *Myrmecaria brunnea*

Safari ants: *Dorylus labiatus*

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Red, black and other types of ants eat as well as carry food material and create annoyance in the kitchen area and house where they crawl in the eatables and other items of use. A few species of the ants also leave formic acid odour in the eatables. Due to their large number, they are able to carry huge amount of food grains from kitchen areas to their nests. Ants live in extremely well developed as well as organised communities. Ants inhabit colonies with very clear hierarchical structures. Ants represents an excellent example of how difficult can nature be and how even the smallest creatures live on the basis of specific laws. They are hugely co-dependent for the sake of the survival of their queen and colony.

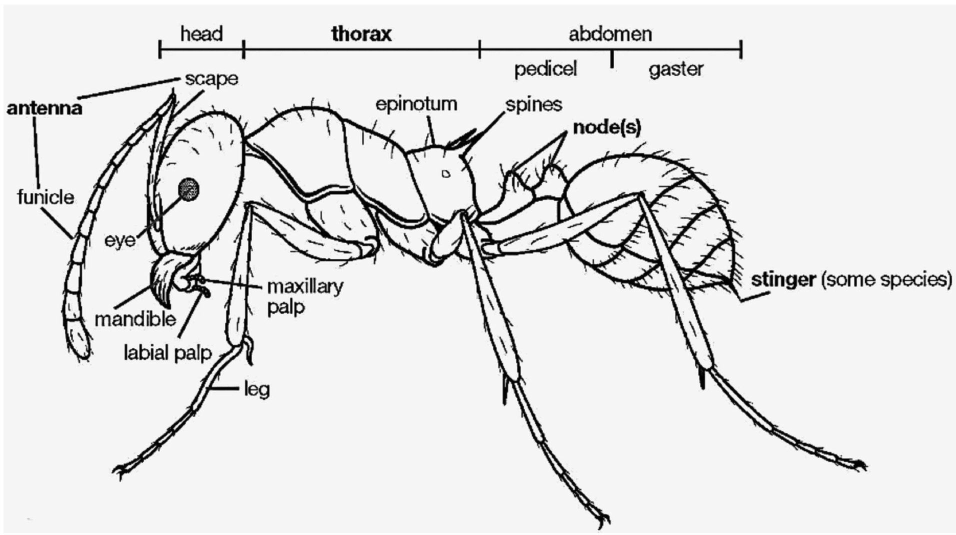

Fig. 3.19 *External Morphology of Ants*

Figure 3.19 is depicting the external morphology of ants. Ants reproduces quickly. They do have highly evolved social systems. Every colony has one queen whose sole responsibility is to produce eggs constantly which lead to the growth of the colony. The rest of the female population, known as worker ants, is in fact sterile. The workers have several other essential roles in the colony like taking care of the mother queen and all-new eggs, securing food as well as defending the colony.

As soon as the queen reaches its adult phase, at specific times of the year, generally in the late spring or early summer, the queen ant flies away from her home to look for male ants to mate. In her solitary journey, several ants fall victims to predators, other ants, drowning as well as other environmental setbacks. The queen ant that successfully mates and finds a place to settle, digs her new chamber underground or in trees to lay her first eggs hoping to build a strong colony. The queens of some species can lay up to millions of eggs. Figure 3.20 is depicting different types of ants.

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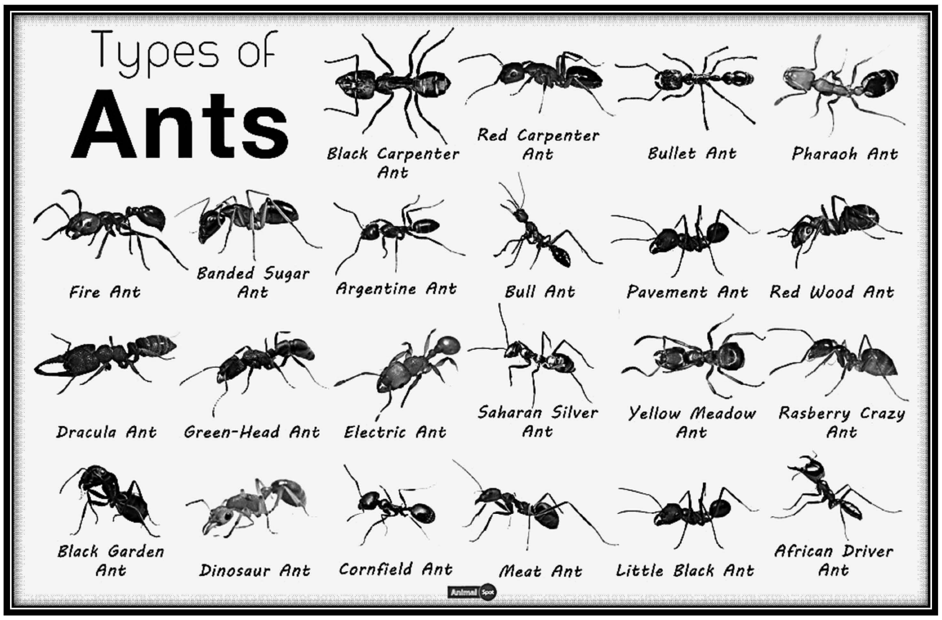

Fig. 3.20 *Different Types of Ants*

The Life Cycle of an Ant

Every ant colony passes via three stages of development. Initially, the queen ant mates and forms her own colony. After, the birth of first workers, the colony goes into the ergonomic stage. The primary focus at ergonomic stage is on the expansion of nest, raising more ant workers as well as conquering new territories. The third stage is referred to as the reproductive one. Here, the colony is strong and stable. The queen has reproduced enough workers to guarantee the survival of the colony. The queen ant will begin producing virgin queens as well as males. Once they enter their adult phase, they will leave the nest at the mating season to begin the entire cycle anew.

Ants are holometabolous type of insects, i.e., they exhibit all the four stages namely: egg, larva, pupa and adult.

(a) Eggs

Initially, after laying the first eggs in its new nest, the queen ant takes care of them. At this time, she utilizes her stored fat reserves as well as wing muscles for nourishment. After the emergence of first adults, they take over the responsibility of tending to the eggs as well as larvae.

The ant eggs are tiny and oval in shape. They are approximately 1 mm long and 0.5 mm in diameter, whitish in colour and are transparent. However, the egg from which the queen ant emerges is big as compared to other eggs.

The surface of the eggs is smooth and sticky and hence they cluster together to form a mass which can be easily transported by the workers around the nest. However, the entire egg mass never reaches to the next phase of development as few of them do not develop and thus become food for the queen as well as the larvae. The queen can lay two different types of egg i.e., fertilized eggs and

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unfertilized eggs. The fertilized eggs develop into female ants like other queens, workers, soldiers, on the contrary, unfertilised eggs will hatch to form male ants. Once the queen has produced enough eggs and her colony has a stable population, ultimately, she will lay eggs that will develop into new queens as well as males. They will fly off and begin new colonies on their own.

(b) Larvae

The larvae hatch from the eggs after a period of approximately 7 to 14 days. Larvae are transparent and have a worm-like form lacking both eyes as well as legs. At the larval stage, the future ants start feeding with food and juices regurgitated by the adult ants. During the larval stage, they require a constant supply of food which leads to their rapid growth. Future queen ants are fed more when compared to the rest of the larva who will eventually become the workers of the colony or male ants. The larvae show periodic moulting, and with each moult, they grow hairs, some of which are hooked. The hooked hair enables the larva to attach themselves together so that they can be carried easily by the worker ants.

(c) Pupa

As soon as the larva reaches a certain growth stage, it forms a silk-like cocoon around itself and pupates. Further, it takes around 30 days for the larva to undergo transformation into the next stage of development. During this phase, the ant undergo metamorphosis into its adult form. In fact, pupa represents the resting stage of development. However, a lot of metabolic activities takes place inside the pupa. Pupas are white, waxy on the outside and slowly become darker in colour. As soon as the pupa becomes dark in colour, it begins the forming of the ant's antennae and legs, which are folded against its body. The pupae of some species spin a cocoon for protection, on the contrary others remain uncovered, or naked.

However, there are exceptions like in few ant species – like the *Lasius niger*, which does not undergo metamorphosis into pupas.

(d) Adult

The entire cycle of the ant, i.e., from egg to the final adult stage last from six to ten weeks. The baby ants that come out of the pupas are very usually pale, soft and weak. However, a couple of hours after emergence, their exoskeleton hardens and they change their appearance by getting darker. On the basis of species, ants can be black, red or brown. The adult possesses six legs, and a body which is segmented into three parts namely the head, thorax, and abdomen. They bear mouthparts on their heads, which they use for eating as well as excavating and two antennae which are sensory in nature. Antennae are essential for the ants' sense of smell and touch. Worker ants use their sense of smell to lead other ants to sources of food, to recognise friends or enemies, and to establish territorial boundaries. After the final metamorphosis, the ants begin their next phase as workers or soldiers, queens and males.

Ants Hierarchy and Castes

(a) Queen Ants

A few queens may survive up to 15 years, or sometimes even decades, if the conditions are favourable. Initially, every queen possesses wings to fly away in pursuit of males to mate. A queen may copulate with several males during her brief mating period; however, after that she never mates again. The queen stores all the sperm in an internal pouch located near the tip of her abdomen known as spermatheca. Inside the spermatheca, sperm remains immobile until she opens a valve that allows it to enter her reproductive tract to fertilise the eggs.

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As the queen settles down to lay her eggs and form a new colony, she will tear off her wings as she no longer requires them. Queen uses her wings only once for her first and only flight. For the rest of her life, queen stays in her nest laying eggs. The workers attend to all the needs of queen. The queen is the most important ant in the colony. In fact, she is the mother of all the ants occupying the nest. If the queen dies the colony will come to an end. There will be no new eggs to replace the dying ants.

(b) Reproductive Male Ants

The male ants possess wings and hence their sole purpose, is to reach adulthood, is to fly away as well as to mate with queens. Male ants generally survive only for two weeks. Male ants are of the same size or sometimes a bit bigger as compared to the worker ants and possess small heads with large eyes. After mating with females, they die. They do not any other purpose or responsibility of the nest.

(c) Worker Ants

Worker ants lack wings and usually survive several months with few exceptions of workers who can survive up to seven years. They cannot reproduce. On the basis of their age, they perform different duties in the nest.

Generally, the young workers stay close to the queen and look after her. The other ant workers are busy with building and expanding the nest, gathering food and making sure the queen is always taken care of and safe.

One of the most important duty for the workers is to control the nutrition of the young larvae. The quantity and quality determine the fate of the fertilized eggs.

Control of Ants

- Ant pans should be used regularly to protect eatables from the ants.
- Baiting with thallous sulphate as well as thallium sulphate or sodium arsenite kills ants.
- Nest should be located and fumigated with carbon bisulfide.
- Dusting of the floor and ant trails with 5% dust of chlordane, BHC, diazinon and lindane is an effective method to get rid of them.

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2. Termites

Termites eat away any wood article, paper, plants as well as animal products. They are responsible for destroying doors, windows, cupboards, almirahs, etc. Over the years, termites are also referred to as the wood bugs as they have destroyed structures and households. Termites are cellulose-eating insects that fall under the infraorder Isoptera and showcase an incredible social system, as seen in ants as well as bees. Isoptera in Greek means 'two-pairs of straight wings', and over the years, termites are sometimes referred to as white ants or confused with true ants. Termites are known to survive mostly in warm and humid temperatures. Some African termites are also considered to be advanced termites, living most of their lives in soil. Approximately 20 species of termites are spread across the lands of America, Europe, Africa and Australia. Later on, researchers indicated the differences between termites and ants. Termites comprises of a large number of species, approximately 2,750 species that are conspicuously found in tropical rainforests worldwide. Transportation for these insects was easy, as they were occasionally transported via wooden pieces such as boat timbers, furniture and shipping crates. Termites are surviving for more than 120 million years. Figure 3.21 is depicting the external morphology of termite

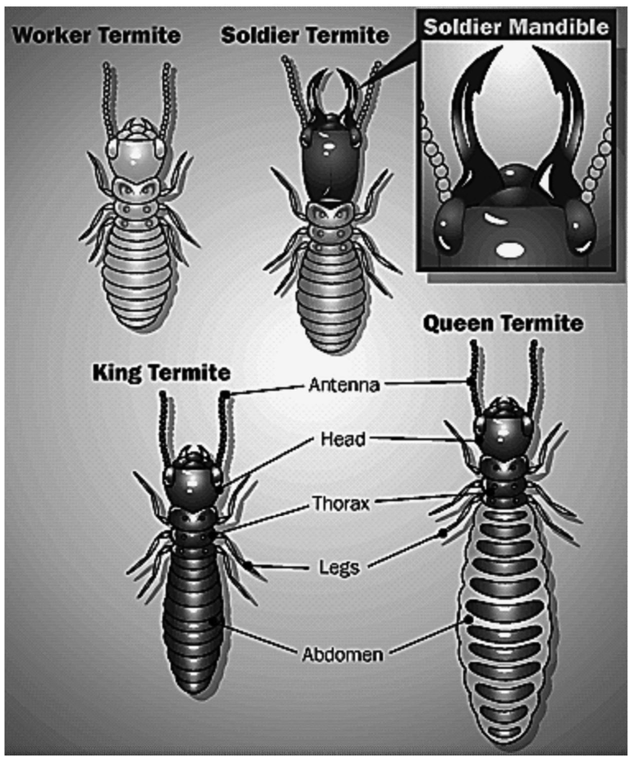

Fig. 3.21 *External Morphology of Termite*

Life Cycle of Termite

(a) The Egg Stage

The female termite lays eggs after fertilization in a jelly-like liquid that holds the eggs together. A female termite can lay approximately 30,000 eggs in a single day. Termite eggs are small and white in colour and hence can be observed via the naked eye. Later, these eggs are incubated for several weeks before they hatch into larvae.

(b) The Nymph Stage

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These nymphal stages appear to be pale, white, and bear tiny exoskeletons. These nymphs emerge with antennae and six functional legs. The nymph develops by moulting, bypassing through instar stages as they mature. During the process of moulting, the nymph termite removes their outer skin as they become very tight. The hormonal indicators decide which caste the nymph evolves into eventually. Later on, the nymph termites come out bigger and developed. Termites here undergo several instars before they reach sexual maturity. The number of instar stages varies, depending on the species of termites.

(c) The Adult Stage

Termites form large colonies and adults of colony are divided into different caste. The colonies include workers, reproductive and soldier termites.

- **Worker Termites:** The body colour of the worker termites varies from yellowish white to creamy white. Majority of the young termite insects develop into worker termites, which is considered as the largest termite colony. Worker termites lack eyes, wings, and are larger in size when compared to the nymphs. In a few termite species, workers are the only termites who can feed independently.
- **Soldier Termites:** The soldier termite comes after worker termites, as they represent the second largest colony of termites. Soldier termites are able to defend themselves and majorly work towards guarding the nest. Soldier termites have the most characteristic features. The mouthparts of soldier termites are specially designed for defence purposes. Soldier termites are sterile as well as blind. They release a toxic substance via their nozzle on encountering an enemy. Soldier termites are regarded to be the most active kind of termite in the colony.
- **Reproductive Alate:** In a termite colony, the only adults that are capable of reproducing are king and queen termites. Reproductive alates that appear to be golden to dark brown are also referred to as swarmers. While some alates are dark-brown in colour, the other termite species of alates are reddish-brown in colour. Alates are bigger in size when compared to both soldiers as well as workers.
- **King Termite:** A male alate who has finished mating is known as king termite. A king termite does not change in size after becoming the king of a colony.
- **Queen Termite:** Over a period of time, queen termites become much larger when compared to king termites. The former reproductive alates are known as queen termite. The ovaries of queen termites develop continuously as she grows older. Due to this, a queen termite is able to lay large amounts of eggs. As the queen termite lays her eggs, her abdomen also gets swollen with time. Figure 3.22 is depicting the life cycle of termite.

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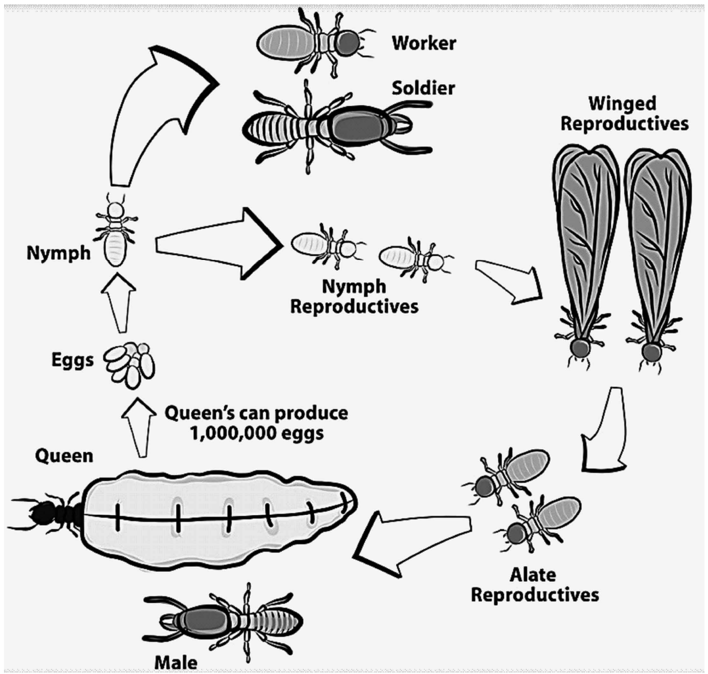

Fig. 3.22 *Life Cycle of Termite*

Control measures for Termites

- Pressure impregnation of creosote, coaltar, zinc chloride, mercuric chloride, sodium fluosilicate, dieldrin etc. helps to get rid of them.
- Wood can be immersed in the insecticide solution for 24 hours to make them termite resistant.
- Soil treatment should be done with dieldrin or BHC before the construction of house in order to keep the termites away from the buildings.
- Termite nests can be destroyed by pouring in them a mixture of dieldrin and kerosene.

3. Furniture Beetles

They are also known as the powder-post beetles or house borers in India. The life span of the female adult varies from 10-14 days whereas that of male varies from 3-4 days. Prothorax covers the deflexed head region, antennae are clavate, usually 11-segmented and elytra completely cover the abdominal region. Both adults as well as the grubs' stages damage the wood reducing it into powder. They cut galleries inside wood and make it weak that it breaks easily with slightest of pressure.

When the adult emerges from the timber, they leave behind a hole about 1-1.5 mm long, along with some dust, which is a revealing sign that an infestation has taken place.

Life cycle of Furniture Beetles

One of the most common type of furniture beetle is a member of the family of *Ptinidae beetles*, which was first discovered by Swedish entomologist Baron Charles de Geer in the year 1774.

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(a) Egg

Females will either lay their eggs in timber cracks or previous holes left behind after excavation.

(b) Larva

The larvae are creamy-white in appearance and are C-shaped. Initially, larva area 1mm long, and they bore into the wood of the host plant as well as feed on the starch present in timber for approximately 3-4 years, growing up to a size of 7mm.

(c) Pupa

When pupation begins, it will approach the surface of the wood and make a small hole. On average, 8 weeks are required for pupation.

(d) Adult

The size of the adults varies from 2.5 -5 mm. They are brown in colour.

The pro-thorax region of these beetles resembles the cowl of a monk. Figure 3.23 is depicting the life cycle of furniture beetle.

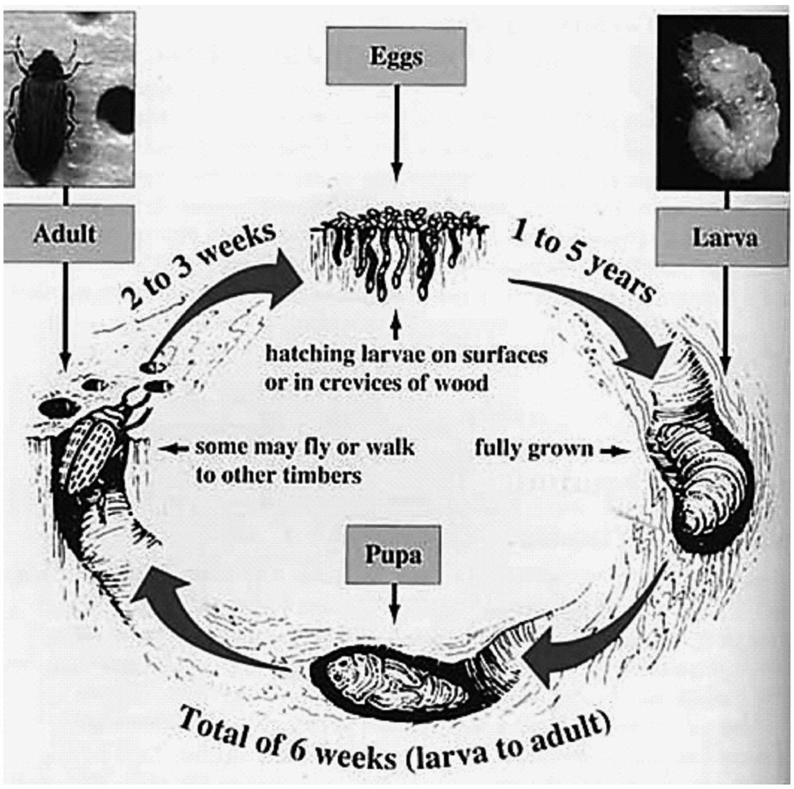

Fig. 3.23 *Life Cycle of Furniture Beetle*

Control Measures for Furniture Beetle

- Treatment of wood with copper sulphate or zinc chloride before making furniture prevents the damage.
- Infested wood can be dried at a temperature of 80-90 degrees to kill all stages of the insects present inside the wood.

- Fumigation by inserting cotton swabs soaked in chloroform or methyl bromide into the galleries also kills the larvae as well as adults inside.
- Regular varnishing as well as polishing of furniture is always a good preventive measure.

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4. Spider Beetles

Even though the different species of spider beetles differ in physical appearance from each other, majority of them exhibit some resemblance to spiders upon first glance. The color of the Spider beetles varies from reddish brown to black to pale yellow or cream in color with distinctive markings that depend on the specific species. They are oval or cylindrical in shape with globular abdomens and hidden heads. Spider beetles are approximately 2-4 mm long and possess long legs as well as antennae. The antennae are 11-segmented antennae and hence are placed closely in front of the legs. Body of the spider beetles is covered with short hairs. They feed on a variety of stored products. The peak breeding season for spider beetles is in late spring or summer. If the climate is favorable they can produce almost two generations in one year. A single female spider beetle can lay around 120 eggs in the span of just one month. The life cycle of a spider beetle is broken down into 4 stages:

- **Egg** – spider beetle eggs will hatch within a month after being laid.
- **Larvae** – the larval stage lasts around 6-8 months.
- **Pupa** – the shortest stage lasting just one month.
- **Adult** – spider beetles will live up to a whole year after reaching adulthood.

There are majorly two types of spider beetles namely: - American and Smooth Spider Beetle and Whitemarked Spider Beetle. Both these beetles have a dark reddish brown shade or completely black colored body. The average length of these spider beetles is around 1.5 to 3.5 mm. American spider beetles possess a head, thorax, legs, and antennae which are most of the times covered with cream or yellow-colored hairs. On the contrary, Smooth spider beetles have a smooth, single-colored, shiny black body. As suggested by the name, whitemarked beetles have patches of white-colored hairs all across the wings while the rest of their body is light-brown in colour. As these beetles get older, their hairs lose their white colour. The average body size of these spider beetles ranges from 2 – 4.3 mm. The presence of an adult spider beetle or a pupal cocoon is the sign of infestation by beetles. Additionally, the foraging pests generally leave behind accumulations of granular materials in pantries as well as around food supplies.

5. Silver Fish (*Ctenolepisma*, *Lepisma saccharina*, *Thermobia domestica*)

They are silvery grey dorso-ventrally flattened stream-lined creatures that are approximately one cm in length. The tip of the abdomen possesses three long thread-like cerci. Silver fish are quick in movement and crawl on the walls as well as hide behind the pictures. They are most commonly seen on walls and prefer to feed on starch, cloths, and fabric, book-binding, pictures, etc. This leads to holes in papers pictures as well as books. Dark as well as damp places are generally favoured by the silver fish and therefore their population goes up during the rainy

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season. The entire life cycle can take up to 2 years and longevity of adults is around 1-3 years. Silver fish can be controlled by spraying carbamates like carbaryl, baygon etc. which kills them quickly. Further, dusting with 5% carbaryl is also effective. Baits can be prepared by mixing oatmeal as well as sodium fluoride, paris green or white arsenic and sugar. Therefore, regular cleaning as well as ventilation for drying is an effective methodology to bring down the population of silver fish. Figure 3.24 is depicting the life cycle of Silver fish.

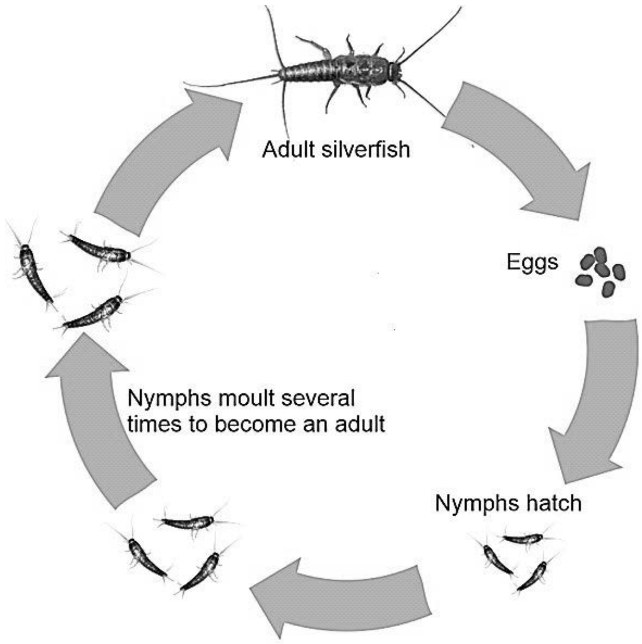

Fig. 3.24 *Life Cycle of Silver Fish*

6. Carpet Beetles

They are also known as spotted carpet beetles as they possess bands of different colour. Larvae of carpet beetles are reddish-brown in colour, approximately 6.0 mm in length, hairy structures with presence of long hairs on the posterior side. *Attagenus pellio; A. piceus,* are known as black carpet beetles. Larvae are hairy, golden-brown in colour and 1.0 cm long. They are small beetles having oval body, body covered heavily with hairs, 2-5 mm in length and with a small head having a median ocellus. Antennae are short and capitate. Tarsi are 5-segmented. Larvae are dark brownish to black in colour and possess long brownish hairs and therefore are popularly known as "Woolly bears". Their cast skin is also hairy. Both larvae as well as adult stages of carpet beetles bite causes holes in clothes, carpets, woollens, padding of furniture, curtains, fur etc. They also attack museum specimens, stuffed animals, dried meat etc. frequently. One of the easiest method of controlling carpet beetles is Fumigation with paradichlorobenzene and naphthalene and spray of stainless insecticides like perthane and methoxychlor or dusting the corners with dieldrin or BHC helps to eradicate them. Control measures are especially important to be undertaken during summer and rainy months. Figure 3.25 is depicting life cycle of carpet beetle.

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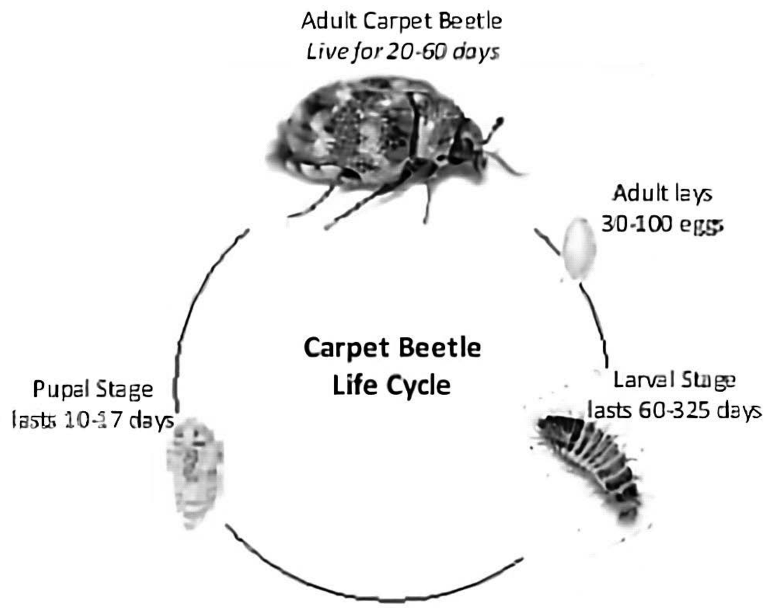

Fig. 3.25 *Life Cycle of Carpet Beetle*

7. Clothes Moths

Clothes moths are small insects of dull colour, having a wing span of one centimetre and frequently fly about in houses. Larva is approximately 2 cm long, which is enclosed in a greyish silken case which it drags along while crawling on the walls, floors etc. Pupation also takes place inside the case, pupal period being about 10 days. The life cycle completes within six weeks under warm and moist conditions. Larva attacks wool, hair, feather, fur, dead insects, dried animals, fish meal, milk powder, leather etc. Clothes as well as other fabrics must be thoroughly dried up and then dusted with insecticides. Fumigation with paradichlorobenzene, naphthalene or camphor and spray of insecticides, for instance: Perthane, Methoxychlor, Malathion, etc., effectively kills the larvae as well as adults.

8. Crickets

Acheta (Gryllus) domestica, can be seen in fields as well as homes. Both male as well as females are winged. Cerci are long and hind wings also pointed forming a tail-like structure. ***Gryllodes sigillatus* are** dull and straw-coloured with brownish patches on body as well as legs and with a brown streak on the head. Female is wingless and male are winged. Abdomen has cerci in both sexes and female has a long ovipositor in the middle. ***Gryllotalpa Africana,*** the male cricket possess fore limbs which are modified for digging purpose and hind legs which are adapted for jumping. It lives in burrows and feeds on the roots of plants. It comes out in the night. Crickets are found in dark and damp places in kitchens, crevices and cracks in the houses. Crickets are nocturnal and feed on a variety of food materials and damage clothing. They are omnivorous and therefore damage almost any article of use in the houses. They also stain the articles as well as clothing with faecal matter. In the night time, they annoy by making huge noise. Crickets breed in rainy season as well as autumn season and lay eggs in damp cracks and crevices. Eggs hatch in a period of 8-10 days. Nymphal period is approximately 6 weeks during which they undergo 8-9 moults. Crickets can be controlled by spraying carbamates, Baygon, lindane, malathion, endosulfan etc. Maintenance of hygiene as well as dry conditions in homes keeps them away. They can be trapped in large numbers in a jar having starchy sweet vinegar, mixed with insecticide, white arsenic or paris green. Figure 2.26 depicting life cycle of crickets.

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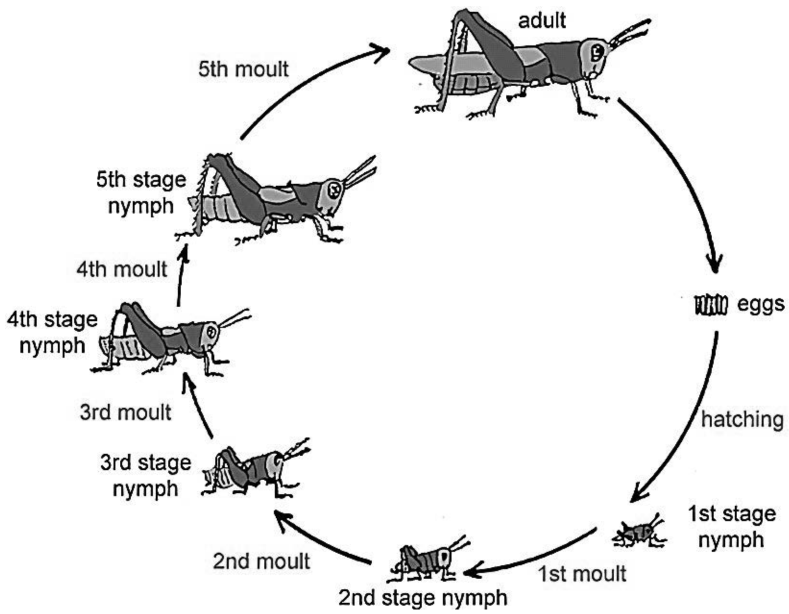

Fig. 3.26 *Life Cycle of Crickets*

9. Book Lice (*Liposcellis transvalensis; L. divinatorius*)

Book lice belong to the order Psocoptera and prefer to live in dark, damp places in houses libraries as well as museums. Book lice are tiny pale whitish insects, they are 1-2 mm in length, soft bodied insect, lacking wings as well as cerci. Antennae are short filiform whereas hind femora are enlarged. Book lice lay extraordinary egg that measures approximately one-third of the body length. In the night time, they make ticking sound due to which they are also known as "death watch". Book-lice are omnivorous and feed on a variety of substance like fungi, stored products, book binding etc. Book lice survive on animal as well as vegetable debris, paste, fungi, glue, dry botanical and zoological specimens etc. They have been recorded to seriously damage tea packed and stored in damp godowns in Assam. They are especially plentiful in the old unused books, whose paper and binding they damage.

One of the ways for controlling book lice includes dusting the places with any insecticide. Fumigation of the surface with sulphur dioxide or HCN gas or ethyl acetate kills them quickly. In-depth cleaning as well as drying or heating of infested articles up to a temperature of 60°C gives relief in mild infestations.

3.2.7 Pest of Pulses

There are several insect pests that attack pulses. All these insect pests can be categorized as flies, bugs, mites, worms, etc. The common pest of pulses are aphids, thrips, cutworms, armyworms, beetles, earworms, spider mites, stem borers etc. In this section, we shall discuss the pests of pulses:

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1. Leaf Miners

They are very destructive pests that can suck sap and feed on the leaves, causing white tunnels or trails on the crop. Leaf miners are particularly harmful to beet, spinach, and chard. The color of the adult insect varies from white to grey colour whereas the larva or maggot is a greenish yellow caterpillar having a pair of black mouth hooks. Leaf miners can be controlled by a suitable insecticide or by using biological sprays or mechanical methods. Figure 3.27 is depicting the life cycle of leaf miner.

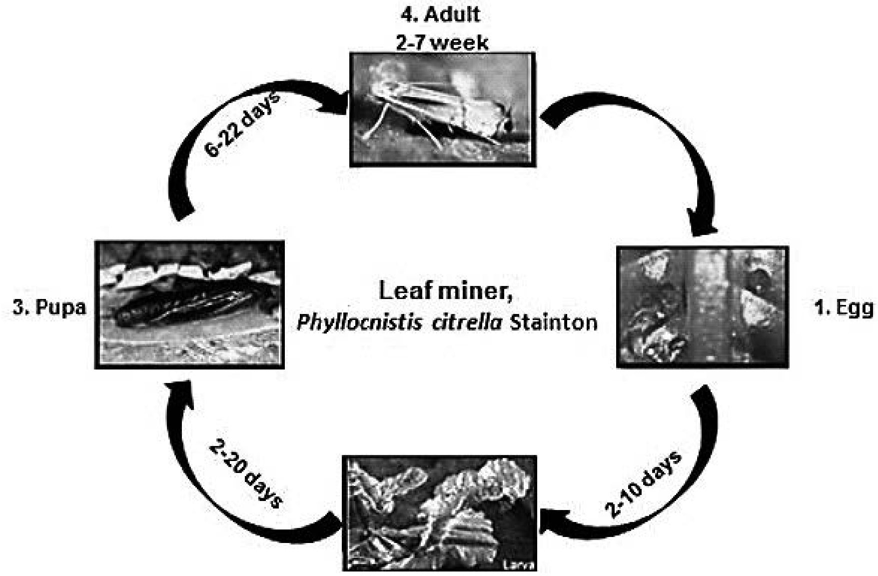

Fig. 3.27 *Life Cycle of Leaf Miner*

Distribution and Status: Throughout India

Host Plants: Blackgram, greengram, cowpea.

Damage Symptoms

Tiny larvae bore into the epidermis of the leaf and forms blisters through mining.

Management

Spray the infested crop with endosulfan 35 EC 2.0 L or methyldemeton 750 ml in 700 litre water per ha.

2. Aphids

Aphids are small pear-shaped insects having long sucking mouth parts. The color of the aphids varies from green, pink, orange, or dark red in color. They suck sap from the leaves as well as stems causing leaf cupping/curling and stunted plant growth. Aphids can also transmit diseases like mosaic and sooty mold. They are popularly known as plant lice. Aphids can be controlled by mechanical methods, biological sprays or by applying insecticides.

Bean Aphid: *Aphis craccivora* (Aphididae: Hemiptera)

Bean aphid is a greenish black coloured aphid. The entire life cycle completes within 3-8 days. Bean aphid reproduces parthenogenetically and viviparously.

The female may produce 8-30 young ones in a life span of approximately 10-12 days. The nymphs transform into adult in 5-8 days after passing through four instars. Figure 3.28 is depicting the life cycle of bean aphid.

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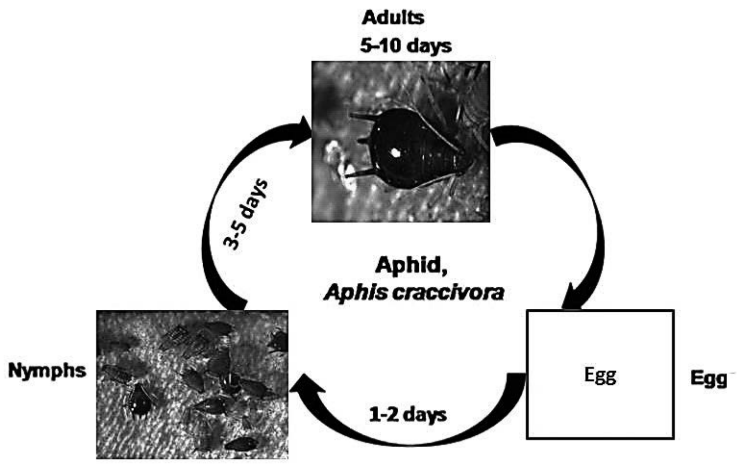

Fig. 3.28 *Life Cycle of Bean Aphid*

Distribution and Status

Cosmopolitan, India, Africa, Argentina, China, U.S.A., Europe, Australia

Host Range

Groundnut, red gram, peas, beans, safflower, lablab, niger

Damage Symptoms

Both nymphs as well as the adult stages cause the damage by sucking the plant sap. Infested pods become deshaped, withered and malformed. Heavy infestation may leads to complete drying of affected pods. They also act as vector of pea virus.

Management

Management practices involves growing resistant cowpea cultivars like P 1473, P 1476, MS 9369, Bendel Lobia. Use entomopathogenic fungus *Fusarium pallidoroseum or Beauveria bassiana* to cause epizootics in aphids in the cowpea field.Spraying of infested crop with 500 methyl demeton 25 EC or dimethoate or 125 ml imidaclorpid in 500 L water per ha effectively control the aphids.

3. Thrips

Thrips are minute winged insects that feed on the leaves as well as flowers causing tiny spots, lesions, and downward leaf curling. They multiply very fast and kill crops within two weeks if they are not well controlled. The light green, yellow, or black insects move in large numbers and can cause heavy damage to vegetable gardens. Thrips can be controlled by applying pesticides, garlic fire sprays or predators like mites and lacewing larva. Figure 3.29 is depicting the life cycle of thrips.

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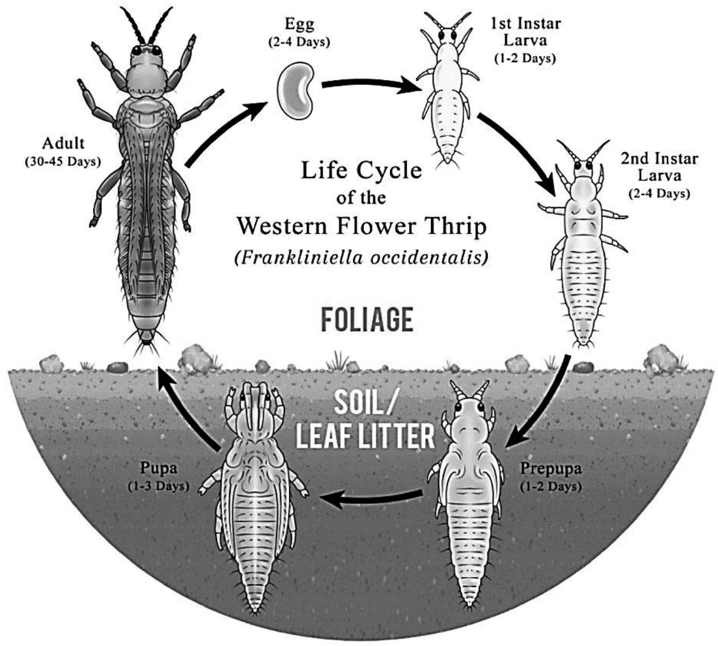

Fig. 3.29 *Life Cycle of Thrips*

Damage Symptoms

The leaves are mottled with specific silvering due to the attack of insect particularly under dry spell on lab lab, black gram, green gram, cow pea. Later leaves dry and shed. Damaged plants do not develop pods. It also acts as a vector of many diseases.

Management: Spray Malathion 50 EC 1.0 L or Carbaryl 50 WP 1.0 kg in 700 L water.

4. Cutworms

The larval forms of cutworms are more destructive as compared to adult. They cut the stems and leaves of seedlings as well as soft crops. The adult cutworms are large-bodied, dark moths having grey wings. There are three types of the larva, black, granulate, and variegated, and all feed on the leaves, stems, and roots. Larvae of Cutworms can be controlled by applying specific insecticide. They can also be killed by parasitic wasps and flies, ground beetles, and beneficial viruses and fungi. Further, cutworms can be managed by practices like weed control, debris removal, as well as late planting.

5. Armyworms

The most common vegetable armyworms are beet and southern armyworms. Adult moths are brownish-gray in colour and damage vegetables via laying eggs on the flowers as well as leaves. The larva of armyworm is more destructive when compared to the adult form. It bores holes on the crop crown and feeds on the plant tissue. Armyworms can be managed by applying insecticides or by worm predators, parasitoids or beneficial bacteria, viruses and fungi. Figure 3.30 is depicting the life cycle of armyworm.

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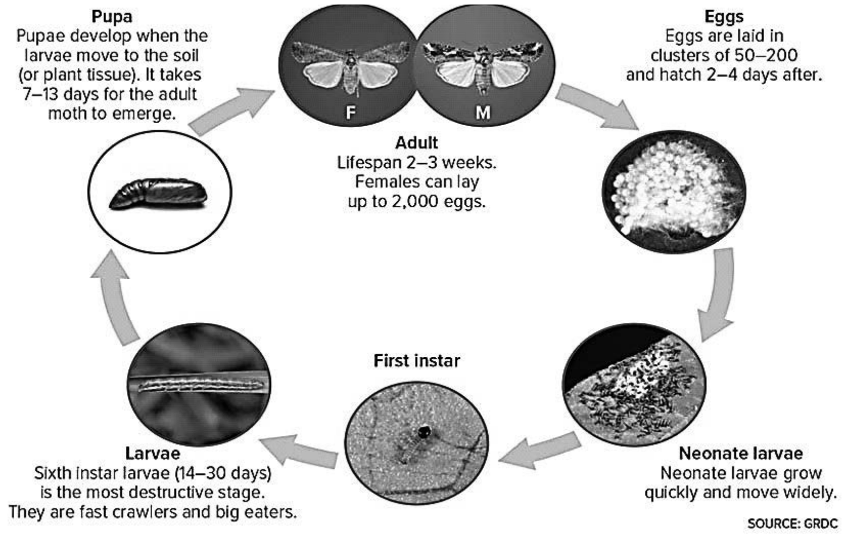

Fig. 3.30 *Life Cycle of Armyworm*

6. Whiteflies

Whiteflies comes under the family Aleyrodidae. They are found in abundance on the abaxial surface of leaves. They generally are referred to as whitefly because of the deposition of a white-coloured wax on their surface (Gullan *et al.,* 2003). Except the first instar which is referred to as crawler, second, third and fourth instars are sessile. Identification of species in case of whiteflies depends on fourth instar which is quiescent and referred to as puparium. Adult emerges out from the fourth instar. They are the most notorious insect attacking many ornamental crops as well as major field crops like cotton leading to huge economic loss. The damage is done due to secretion of honey dew on the surface of leaves which leads to development of moulds on the surface of leaves and thus affects the rate of photosynthesis. Moreover, they also serve as the vector of viral diseases. Figure 3.31 is depicting the life cycle of whitefly.

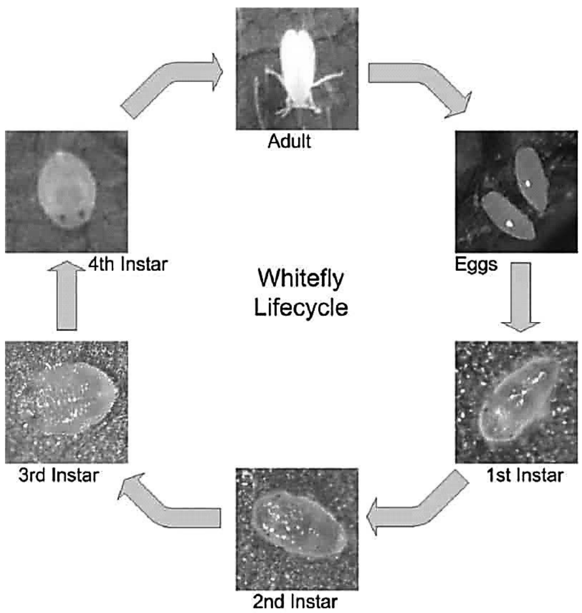

Fig. 3.31 *Life Cycle of Whitefly*

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Management Practices

- Grow black gram resistant varieties like ML 337, ML 5, MH 85-61, ML 325.
- Spray the infested crop with Malathion 50 EC 1.0 L or Phosalone 50 EC 750 ml or Dimethoate 30 EC 750 ml in 700 - 1000 L water per hectare.

7. Green Leafhopper: *Empoasca kerri, E. binotata, E.flavescens* (Cicadellidae: Hemiptera)

These pests are elongate, active wedge shaped green insects which are frequently seen on the under surface of leaves. The adult female inserts its eggs inside the veins of leaves. The incubation period generally lasts for 4-8 days. There are five nymphal instars occupying 7-10 days.

Host plants: Green gram, black gram, cowpea

Damage symptoms: The nymphs as well as the adults feed on tender leaves and other parts of the plant by sucking the plant sap. In cases of severe attack, leaves become brittle and dry. Specific features like hopper burn i.e., cupping of leaves appear. The plant may lose its strength leading to poor growth.

Management: Spray the infested crop with methyl-o-demeton 750 ml in 700 - 1000 L water per hectare.

8. Redgram Scale: *Ceroplastodes cajani* (Coccidae: Hemiptera)

Tender branches are covered with scales attended by ants. Adults are round waxy scales.

9. Redgram Leaf Roller: *Caloptilia soyella* (Gracillaridae: Lepidoptera)

Leaves rolled up apically and become whitish in colour and dries up. Adult moth is very small in size. Larva is creamy yellow or greenish in colour with sparse hairs on the body.

10. Leaf Folder: *Anticarsia irrotata* (Noctuidae: Lepidoptera)

Larva folds the leaves together. Adult is yellowish brown colored moth with oblique black lines on the wings. Larva is green coloured.

11. Leaf Eating Caterpillar: *Azazia rubricans* (Noctuidae: Lepidoptera)

The larva causes serious defoliation. Larva is greenish in colour, slender in shape having ashy white band between each segment. A few narrow lines along the back and bright yellowish brown stripes along the sides may or may not be present. It shows looping movement in spite of the presence of all prolegs. Adult moth resembles a dry leaf.

12. Sphingid Caterpillar: *Acherontia styx* (Sphingidae: Lepidoptera)

The larva of this pest feeds on leaves and thus leads to serious defoliation. Adult is very large in size, having grey colored wings with waxy markings. Abdomen is crimson coloured with black stripes. Larva is a stout green caterpillar having yellowish oblique stripes with curved anal horn.

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13. Leaf Cutter Bee: *Megachile anthracena* (Megachilidae: Hymenoptera)

These are medium sized brown colored bees. Red gram leaves exhibit semicircular or circular cut out. Adults cut small bits of leaves for making larval chambers. Table 3.3 is summarizing the major and minor pests of pulses.

Table 3.3 *List of Major Pests*

Major pests				
1.	Bean aphid	*Aphis craccivora*	Aphididae	Hemiptera
2.	Thrips	*Ayyaria chaetophora, Caliothrips indicus, Megalurothrips distalis*	Thripidae	Thysanoptera
3.	Whitefly	*Bemisia tabaci*	Aleyrodidae	Hemiptera
4.	Green leafhopper	*Empoasca kerri, E. binotata, E.flavescens*	Cicadellidae	Hemiptera
5.	Pod bug	*Riptortus pedestris Clavigralla horrens Clavigralla gibbosa Anoplocnemis phasiana*	Coreidae	Hemiptera
6.	Lablab bugs / stink bug	*Coptosoma cribraria*	Coremelanidae	Hemiptera
7.	Leaf webber	*Eucosma critica*	Eucosmidae	Lepidoptera
8.	Lab-lab leaf miner	*Cyphosticha coerula*	Gracillariidae	Lepidoptera
9.	Termites	*Odontotermes obesus*	Termitidae	Isoptera
10.	Redgram scale	*Ceroplastodes cajani*	Coccidae	Hemiptera
11.	Redgram leaf roller	*Caloptilia soyella*	Gracillaridae	Lepidoptera
12.	Leaf folder	*Anticarsia irrotata*	Noctuidae	Lepidoptera
13.	Leaf eating caterpillar	*Azazia rubricans*	Noctuidae	Lepidoptera
14.	Sphingid caterpillar	*Acherontia styx*	Sphingidae	Lepidoptera
15.	Leaf cutter bee	*Megachile anthracena*	Megachilidae	Hymenoptera

Check Your Progress

1. Name some common pests of cotton.
2. What is the common name of Pyrilla perpusilla?
3. How many nymphal instar stages Pyrilla perpusilla passes through to reach the adult stage?
4. Write the name of one major pest of paddy.
5. Name some natural enemies of mango hopper.
6. Which insects are called holometabolous type of insects?

3.3 INSECTS PESTS- MANAGEMENT, STRATEGIES AND TOOLS.

NOTES

Insect pests possess a huge loss to human, nature as well as economy. It can lead to qualitative and quantitative loss of crops. Adopting Insect pest control measures would provide the opportunity to the farmers to control the insect pests before they can cause severe crop damage and huge economic loss. Further, they need to be controlled as they are the vectors of many crop diseases and aids in transferring diseases to distant places.

Insect Pest: Management, Strategies and Tools

Insect pests can be controlled by adopting different methods like:

A. Natural or Cultural methods of pest control
B. Physical or Mechanical methods of pest control
C. Pheromone traps
D. Biological methods of pest control
E. Chemical or modern methods of pest control
F. Genetic method of pest control
G. Integrated Pest Management or IPM measures of pest control

3.3.1 Natural or Cultural Methods of Pest Control

Cultural control of pests includes methods like planting, growing and harvesting crops, which will reduce crop damage. A few methods are discussed below:

1. **By Using Resistant Varieties of Crops**: This methodology involves using the insect pest resistant varieties of crops. A few varieties of crops are highly resistant to insect pests. For instance: Atlas-sorghum is resistant to chinch bug, Pawnee-wheat is resistant to Hessian fly;, rice varieties, namely, IR-36, Pattambi-33, IR-42 are resistant to brown plant-hoppers. Resistant crop exhibits specialized characters like hairy leaves, which might pose great difficulty to potato leafhopper in feeding.
2. **By Ploughing:** This methodology involves using different tillage activities in fields at the preparation time like planking, ploughing etc. to destroy the eggs as well as pupa of different insect pests hibernating in the soil in off seasons. Timely ploughing helps in killing the eggs as well as larval stages of insect pests. It also helps in eradicating the weeds. For instance: Ploughing effectively controls corn root-aphids as it eradicates the weeds upon which they might feed before the main crop is planted.
3. **By Adopting Good Planting Practices:** A few planting practices are as follows:
   (a) **Changing Planting and Sowing Time of Crops**: Insect pests can be managed effectively by simply shifting the sowing dates of crops by few days. For instance: problem of aphids (major insect pest) in wheat crop in Indian sub-continent can be managed effectively by late sowing of wheat just by 10 -15 days than normal dates of sowing.

(b) **By Using the Insect Pest-Free Planting Material**: Sometimes, infected planting material or seedlings are used by mistake for sowing in crop fields. For instance: when infected bolls of cotton are preserved and used for planting in next year.

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4. **By Harvesting Practices:** This methodology involves destroying the remaining debris and plant parts of harvested crops as these plays the role of host plants in the offseason for insect pests. Clean cutting, thorough/ uniform mowing, etc., are generally used to eliminate any leftover plants in the crop fields.
5. **Weed Control**: This methodology involves destroying/removing or controlling the weed plants. Weed plants serves as host plants for several harmful insect pests. For instance: weed plant of *Parthenium hysterophorous* or carrot weed provides food and shelter to different insect pests. Hence, weed control reduces pest infestation.
6. **Destruction of Volunteer Crops:** Volunteer crops refers to those crops that are self-sown or spilled seeds. Such crops should be destroyed. For instance:- spilled seeds of cotton will sprout and produce an earlier crop infected with pink bollworm and when the main crop emerges there is already a substantial population of the pest (pink bollworm) available.
7. **By Isolation the Main Crop from Secondary Crop:** This methodology involves planting the main crop as far away as possible from the other secondary crops. For instance: Armyworms may breed on wheat as well as barley and later may migrate to corn and sorghum.
8. **By Closed Seasons:** A monophagous species can be eradicated effectively by not growing the particular crop for a year or two. Such practices are traditionally followed in tropical countries to reduce the damage caused by pink bollworm.
9. **By Crop Rotation Methodology:** Crop rotation is one of the most effective methodology against pests that feed on comparatively few plant species, and are also incapable of long-distance migration. By following crop rotation, the insect pests which developed and flourished due to monoculture are managed. For instance, by changing the rice-wheat crop pattern, several pests of rice-wheat can be controlled effectively.
10. **Pasturing:** This methodology is employed in area having large number of grazers. Pasturing (grazing/feeding on grass/herbs) in the heavily damaged fields serves two purpose:-
    (a) Remaining plants can be easily utilized as fodder
    (b) Pest stages are destroyed by feeding and trampling by the animal herds.
11. **Fertilizing:** Crops like wheat, barley and oats can survive green bug infestation better when fertilized and irrigated.
12. **Flooding:** This methodology can be employed in rice fields where it is possible to destroy pests by flooding. For instance- flooding destroys several migrating sugarcane pests like armyworms. Ploughing followed by flooding kills pink bollworms in cotton.

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13. **Trap Crops:** As the name suggests, this crop helps in trapping the insect pest. A trap crop refers to the small planting of the vulnerable crop made earlier than the main crop. Trap crop is highly attractive to the insect. 'Trap crop' diverts the insect pest from attacking the main crop. For instance: broom grass is planted around wheat fields in Canada, against wheat stem sawfly, *Cephus cinctus.* Also, planting of mustard on border rows of wheat crop for protecting wheat crop from damage due to aphids.
14. **By Burning Practices**: Burning practices involves destroying the pest affected plant parts in the soil, so that they are not propagated further to distant fields.
15. **By Performing the Mixed or Intercropping Activities**: Intercropping activities reduces the host plants providing food for survival to pests and limits their number.

3.3.2 Physical or Mechanical Methods of Pest Control

Pests can be destroyed mechanically also by employing methods like:

1. **Handpicking Method:** This method involves picking and crushing/killing the pest with the help of hands only or by using common/simple tools. For this, stakeholder must visit plants daily or several times in a week to monitor the presence of pests. Careful observation leads to successful handpicking of the pests. This methodology can be employed when:-
   (a) There is low pest infestation.
   (b) Pest is highly visible.
   (c) Cheap labour is available.
   (d) All the pest stages can be destroyed by hand.

   A few examples where handpicking technique can be employed effectively are as follows:
   (a) Locust nymphs which are assembling can be beaten by sticks and brooms.
   (b) Handpicking of *Papilio* larvae from citrus plants, sugarcane borer eggs, sawfly larvae on mustard, cabbage butterfly eggs etc. are very effective in small areas.
2. **Burning Method:** Field burning (Controlled burning) is a more traditional method of controlling pest. Traditionally, after the harvest, the entire field is burnt to kill any harmful species including eggs which may have been left. This type of pest control clean the field to the core. For instance: Trash and garbage, weeds etc. are collected and burnt to destroy pest stages. Flamethrowers are used to burn locust hoppers as well as adults that are congregating.
3. **Trapping Method:** This is the most common strategy employed by researchers/farmers/entomologist, etc. This method aims at attracting the insects to bait, light etc. in order to kill them. This methodology is usually employed to collect insect as well as to determine the infesting insect

population. A few traps are discussed below:-

- **Yellow-Pan Traps –** This trap contains water and few drops of oil which are scientifically proven in killing hopper adults on paddy/sugarcane/ wheat crops etc.
- **Sticky Traps-** Sticky traps are boards of yellow color smeared with a sticky substance. This sticky substance helps in trapping and killing the flying insects that are attracted to the board.
- **Pitfall Traps –** Pitfall traps are pan-shaped containers having insecticide and embedded below the ground level. Pitfall traps are generally used to catch crawling and fast-running insects.
- **Light Traps-** Light traps attract night-flying insects which are attracted to UV light. They fall into a container containing water, oil or insecticide or sometimes they hit an electric grid.
- **Pheromone Traps**- Pheromone traps are mainly effective against the lepidopteran pests. Females releases certain pheromone to which males are attracted even from a significant distance.

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4. **Barriers:** Barrier method is employed to prevent insects from infesting the crop. Different types of barriers can be used to prevent insect infestation:
   - Cloth screens over seedbeds can protect the younger plants from insects like hoppers, armyworms, flea beetles, etc.
   - Metal collars around young plants protect them from cutworms.
   - Trench barriers are helpful to stop chinch bugs, armyworms, locusts etc.
   - Metal or concrete barriers are frequently used against termites.
   - Barrier spraying of residual insecticides has become more common against the insects like termites and locusts
   - Sticky bands which are applied around mango tree-trunks during the months of December-January helps in preventing the upward movement of mango mealy bugs
5. **Temperature Control Method:** This method is employed for stored grain pests as temperature extremities are fatal to insects. Low temperatures are generally utilized for controlling insects in flourmills and warehouses. Exposing the insects to sub-zero temperature for 24 hours is lethal.
6. **Drying Method:** Insects requires moist conditions to thrive and cannot survive in low moisture conditions. Hence, drying the food grains in sun or using heat blowers can reduce the insect infestation of stored grains.
7. **Radiation Method:** This methodology is employed to kill all the insect stages during export/import of large quantities of fruits, grains as well as vegetables. Gamma radiation are generally used to kills all stages of the pests in storage conditions.
8. **Ultrasonic Vibrations Method:** Insects like moths are often susceptible to bat's ultrasonic signals and hence quickly evacuate the area. Mocking of the bat's echolocation system aids in scaring away the lepidopteran pests from the area of concern.

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3.3.3 Pheromone Traps

Pheromones are the substances that are released into the environment by an individual of a species that elicits a specific social response in members of the same species. They are the chemicals used by insects and other animals to communicate with each other. The composition of the pheromones may be saturated carbonic acid, steroids, aldehydes, ketones, alcohols or other compounds. Insect' uses pheromones as chemical signals to search food, attract mate or warn others of predators. By utilizing particular pheromones, traps can be used to observe or monitor the target pests in agriculture as well as in residential areas. This could lessen damage to agriculture crops, plants as well as damage caused to the residential and commercial structures. This can also limit the presence of stinging insects in the nearby residential areas. Pheromones can also help to find locations where the pests are becoming established. For instance- Insect pests like Asian gypsy moths and Japanese beetles can be damaging to plants and thus can be conveniently limited with the help of such community traps. Pheromones can be classified into following types on the basis of their function:

1. Aggregation Pheromones

- As the name suggests, aggregation pheromones are used to gather together individuals of the same species both males as well as females in moderately large numbers. Thus, aggregation pheromones are used by an organism for task that requires collective efforts such as invading a new habitat.
- These pheromones also perform other functions such as mate selection, overcoming host resistance by mass attack as well as defense against predators.
- Aggregation pheromones are one of the most ecologically selective pest suppression methods.

2. Alarm Pheromones

- Alarm pheromones can trigger flight or aggression in individuals of the same species.
- Alarm pheromones are also used to warn members of the same species about upcoming danger.
- For instance, aphids uses an alarm pheromone to inform other individuals of their species that they were attacked by a predator like lady bug.
- Some plants when grazed upon, results in tannin production in neighboring plants which make the plants less appetizing for the herbivore.

3. Releaser Pheromones

- Releaser pheromones are pheromones that cause an alteration in the behavior of the recipient.
- Releaser pheromone leads to rapid response, however it is quickly degraded.
- For instance, a few organisms use potent attractant molecules to attract mates from a very large distance.

4. Signal Pheromones

- Signal pheromones leads to short-term changes like neurotransmitter.

5. Primer Pheromones

- Primer pheromones trigger a change of developmental events whereas other pheromones leads to a change in behavior.

6. Territorial Pheromones

- Territorial pheromones mark the boundaries of an organism's territory.
- In some animals like cats and dogs, these pheromones are present in the urine and are used to mark the perimeter of the claimed territory.

7. Trail Pheromones

- Trail pheromones are common in social insects such as ants, honeybees etc.
- For instance, ants mark their paths with trail pheromones so that they can follow each other. This trail attracts other ants and serves as a guide to food source for them.

8. Sex Pheromones

- Sex pheromones are involved in the process of reproduction by attracting the opposite sex in animals.
- Release of sex pheromones indicates the availability of the female for breeding.
- Sometimes male animals also emit pheromones that transmit information about their species and genotype.
- Pheromones released by female are used to attract male of the same species.
- Pheromones released by males are used to attract female of the same species.

9. Host-Marking Pheromone

- Host marking pheromones are generally used by parasitoids to avoid ovipositing on hosts.
- Hyper parasitoids may use these host marking pheromones to look for their hosts.

Requirements for Effectiveness of Pheromones Traps: A pheromone trap is used to capture the insect pest using specific pheromones. To ensure the effectiveness of pheromone traps

- Ascertain the quality of lure used for trap.
- Ascertain the quality as well as the specificity of the pheromone.
- Installation of the trap should be done at right time.
- Installation of the trap should be done at right place, i.e., stick/log.
- Installation of the trap should be done at proper height.

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- Proper care of the polythene sleeve should be taken.
- Damaged sleeves should be replaced immediately.
- Proper distance should be maintained between the traps.
- Pheromone lure should be replaced timely for maintaining the effectiveness of the pheromone trap.
- Different types Pheromones- Lures used are: Fiber, Plastic Tube, Rubber Septa, Controlled Release Membrane, Beads, Oil Solutions, Gels, etc.
- Different types of pheromone traps used are: Funnel Traps, Grain Probe Traps, Pitfall Traps, Sticky Traps, Box Traps, Wing Traps, Delta Traps, Diamond Traps and Discreet Trap.

Table 3.4 *Types of Pheromones & their Chemical Structure*

Insect	**Name Of the Pheromone**	**Chemical Structure**
Bombyx Mori	Bombykol	10, 12 Hexa-decadien 1-ol
Porthetria dispar	Gyplure	1 Hexal-12-Hydroxy-3 Dodisenle acetate
Honey Bee	Queen substance	9-oxo-trans-2-decenoic acid
Periplanta americana	-----	2,2 dimethyl-3-isopropylidine cyclopropyl propionate
Mad fly	Singlure	2,3 secondary-butyl 4 chloro 2 methyl hexane
Mad fly	Trimedlure	2,3 ter. butyl
Oriental fruitfly	Methyle eugenol	1, lil,1,2, Dimethoxy benzene
Carda cautelia	----	9, 12 tetradecadien 1-ol acetate
Pectinophora gossypiella	----	10 prophy-trans-5,9, tridecadien 1-ol acetate
Parthetria dispar	-----	D-10-acetoxy-cis 7-hexa decen-1-ol

Advantages of Using Pheromones in Pest Control

- Pheromones helps in controlling urban pests.
- Pheromones helps in monitoring exotic pests.
- Pheromones helps in mass trapping of insects from breeding and feeding potential.
- Pheromones helps in disrupting mating of insect population.
- Very minute quantity of pheromone is required for making pheromones traps.
- Pheromones are non-polluting and ecologically acceptable.
- Pheromones are species specific.
- Helps in easy monitoring of pest population.
- Pheromones are best suited in Integrated Pest Management (IPM) techniques.
- Pheromones are quite cost effective and labour saving.

Disadvantages of Using Pheromones in Pest Control

- Pheromones are yet to be identified in several wild species.

- Sex pheromones are capable of attracting only one sex.
- Farmers are not well equipped with the use of pheromones
- Quick results cannot be obtained with application of pheromones.

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3.3.4 Biological Methods of Pest Control

Biological control refers to the action of natural enemies like parasites, predators as well as pathogens in maintaining another organism's population density at a lower level in nature than would occur normally in their absence. Biological method of controlling insect pest involves releasing predators/ parasites/pathogens which are the natural enemies of insect pests in sufficient number in crop fields.

3.3.5 Chemical Methods of Pest Control

The chemical methods of insect pest are referred to as modern methods of pest control. Different chemicals have different formulations like:

1. Granules (G)
2. Pellets(P)
3. Dust(D)
4. Soluble Powders (SP)
5. Wettable Powders (WP)
6. Aerosols (A)
7. Emulsifiable Concentrates (EC)

All the chemicals can be divided into different categories:-

1. On the basis of mode or site of action:
   - **Systemic Insecticides**: Systemic insecticides act on the stomach of the insect pests and kill them. These insecticides are translocated in the inside tissues of the pests by translocation action.
   - **Contact Insecticides**: Contact insecticides are effective when they come in contact with the insect through their outer body parts.
   - **Fumigants**: Fumigants refers to the chemicals which are used for controlling the stored grain pests by the release of toxic gases in the storage houses.
2. On the basis of different chemical groups:
   - **Organophosphates-** Organophosphates (also known as phosphate esters, or OPEs) are a class of organophosphorus compounds with the general structure $O=P(OR)_3$, a central phosphate molecule with alkyl or aromatic substituents
   - **Organochlorine-** Organo-chlorines include a class of organic compounds containing chlorine (Cl^-) atoms bounded by covalent attachment to the carbon structure
   - **Pyrethroids-** A pyrethroid is an organic compound similar to the natural pyrethrins, which are produced by the flowers of pyrethrums

(*Chrysanthemum cinerariaefolium* and *C. coccineum*). Pyrethroids are used as commercial and household insecticides.

- **Carbamates-** A carbamate is a category of organic compounds that is formally derived from carbamic acid (NH_2COOH). The term includes organic compounds (e.g., the ester ethyl carbamate), formally obtained by replacing one or more of the hydrogen atoms by other organic functional groups; as well as salts with the carbamate anion H_2NCOO^-
- **Bio-pesticides**- Bio-pesticides are certain types of pesticides derived from such natural materials as animals, plants, bacteria, and certain minerals. For example, canola oil and baking soda have pesticidal applications and are considered bio-pesticides.

3.3.6 Genetic Method of Pest Control

Genetic control of insect pest involves the procedure of manipulating genetic material of a pest species so as to confer lethality on the species. Inherited sterility is one of the most common approach used to control insect pest population. It involves genetic manipulation of the pest population in which such a way that the reared and released insects are fertile however their progenies are sterile. This effect is also known by other names such as **delayed sterility**, **F1 sterility** or **partial sterility**. This phenomenon is generally applied on insects belonging to the order Lepidoptera and Hemiptera that contain polycentric chromosomes. Genetic manipulation can also be achieved by incorporating new and potentially deleterious genes (or alleles) into the genetic makeup of a pest population. In effect, genetic control involves transforming a few members of a pest species into biological time bombs that eventually destroy other members of their own species. Due to the self-destructive nature of these tactics, genetic control is sometimes referred to as autocidal control techniques.

3.3.7 Integrated Pest Management Strategies (IPM)

Integrated Pest Management (IPM) refers to the collective methods used for controlling pest. It employs all appropriate methods of pest control to decrease pest populations and maintain them below economic injury level**.** IPM is also referred to as protective management and was originally coined to define the blending of biological control agents with chemical control as these methods when used earlier individually either failed to give good results or led to some serious environmental issues. Therefore, researchers felt the need to merge these two technologies as well as other suitable methods into a unified programme known as IPM or integrated pest management to manage the pest population effectively without harming the environment.

Components/Techniques of Integrated Pest Management (IPM)

Techniques of IPM are as follows:

1. **Cultural Control:** Cultural control of pests includes methods like planting, growing and harvesting crops, which will reduce crop damage. A few methods are discussed below:-
   - By using resistant varieties of crops

- By ploughing
- By adopting good planting practices
- By Changing the planting and sowing time of crops
- By using the insect pest-free planting material
- By following good harvesting practices**:** This methodology involves destroying the remaining debris and plant parts of harvested crops as these plays the role of host plants in the offseason for insect pests. Clean cutting, thorough/uniform mowing etc. are generally used to eliminate any leftover plants in the crop fields.
- Weed control: This methodology involves destroying/removing or controlling the weed plants as they serve as host plants for several harmful insect pests.
- Destruction of volunteer crops
- By isolation the main crop from secondary crop
- By closed seasons**:** A monophagous species can be eradicated effectively by not growing the particular crop for a year or two. Such practices are traditionally followed in tropical countries to reduce the damage caused by pink bollworm.
- By crop rotation methodology
- Pasturin**g:** Pasturing (grazing/feeding on grass/herbs) in the heavily damaged fields serves two purpose: remaining plants can be easily utilized as fodder; pest stages are destroyed by feeding and trampling by the animal herds.
- Fertilizing: Crops like wheat, barley and oats can survive green bug infestation better when fertilized and irrigated.
- Flooding**:** This methodology can be employed in rice fields where it is possible to destroy pests by flooding. For instance- flooding destroys several migrating sugarcane pests like armyworms. Ploughing followed by flooding kills pink bollworms in cotton.
- Trap crops**:** A trap crop refers to the small planting of the vulnerable crop made earlier than the main crop. Trap crop is highly attractive to the insect. 'Trap crop' diverts the insect pest from attacking the main crop. For instance: planting of mustard on border rows of wheat crop for protecting wheat crop from damage due to aphids.
- By burning practices: Burning practices involves destroying the pest affected plant parts in the soil, so that they are not propagated further to distant fields.
- By performing the mixed or intercropping activities: Intercropping activities reduces the host plants providing food for survival to pests and limits their number.

2. **Mechanical Control:** This methodology involves physically/mechanically killing the pest. The strategy can be employed effectively in places of low pest infestation. A few strategies are:

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- **Handpicking Method:** This method involves picking and crushing/killing the pest with the help of hands only or by using common/simple tools. For this, stakeholder must visit plants daily or several times in a week to monitor the presence of pests. Careful observation leads to successful handpicking of the pests. For instance: Locust nymphs which are assembling can be beaten by sticks and brooms. Or handpicking of *Papilio* larvae from citrus plants, sugarcane borer eggs, sawfly larvae on mustard, cabbage butterfly eggs etc. are very effective in small areas.
- **Burning Method:** Field burning (Controlled burning) is a more traditional method of controlling pest. Traditionally, after the harvest, the entire field is burnt to kill any harmful species including eggs which may have been left. This type of pest control clean the field to the core. For instance: Trash and garbage, weeds etc. are collected and burnt to destroy pest stages. Flamethrowers are used to burn locust hoppers as well as adults that are congregating.
- **Trapping Method:** This is the most common strategy employed by researchers/farmers/entomologist, etc. This method aims at attracting the insects to bait, light etc. in order to kill them. This methodology is usually employed to collect insect as well as to determine the infesting insect population.
- **Barriers:** Barrier method is employed to prevent insects from infesting the crop. Different types of barriers can be used to prevent insect infestation. For instance: Cloth screens over seedbeds can protect the younger plants from insects like hoppers, armyworms, flea beetles etc. ; Metal collars around young plants protect them from cutworms; Trench barriers are helpful to stop chinch bugs, armyworms, locusts etc.
- **Temperature Control Method:** This method is employed for stored grain pests as temperature extremities are fatal to insects. Low temperatures are generally utilized for controlling insects in flourmills and warehouses. Exposing the insects to sub-zero temperature for 24 hours is lethal.
- **Drying Method:** Insects requires moist conditions to thrive and cannot survive in low moisture conditions. Hence, drying the food grains in sun or using heat blowers can reduce the insect infestation of stored grains.
- **Radiation Method:** This methodology is employed to kill all the insect stages during export/import of large quantities of fruits, grains as well as vegetables. Gamma radiation are generally used to kills all stages of the pests in storage conditions.
- **Ultrasonic Vibrations Method:** Insects like moths are often susceptible to bat's ultrasonic signals and hence quickly evacuate the area. Mocking of the bat's echolocation system aids in scaring away the lepidopteran pests from the area of concern.

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3. **Biological Control:** Biological control refers to the action of natural enemies like parasites, predators as well as pathogens in maintaining another organism's population density at a lower level in nature than would occur normally in their absence. Biological method of controlling insect pest involves releasing predators/ parasites/pathogens which are the natural enemies of insect pests in sufficient number in crop fields.
4. **Chemical Control:** IPM strategies aims at using minimal insecticides in order to prevent soil pollution or other environmental issues. The basic rule is not to use insecticides unless absolutely necessary. Application methods that do not bring insecticides in close contact with natural enemies are mostly preferred in IPM programmes
5. **Regulatory Methods:** This methodology employs keeping plant and animal under quarantines by the government and collective eradication as well as suppression in large areas help in providing long-lasting management. For instance: this has been successfully employed internationally in suppressing noxious pests like locusts.

Examples of Integrated Pest Management

1. Cotton pest control in Peru: This was developed by Wille in 1951, in Canete Valley. It is a self-contained ecosystem surrounded by arid areas. Cotton pest has developed high resistance to insecticides due to its extensive use over a long period of time and the valley was led to the edge of disaster. In order to save the crops, following steps have been taken:
    - Prohibition of use of synthetic organic insecticides
    - Using old calcium, lead arsenates as well as nicotine sulphates.
    - Adopting biological methods to control pest i.e. introduction of natural enemies from the nearby regions
    - Establishment of time limit for activities like planting, ploughing, irrigation, pruning and harvesting.
    - Adopting healthy cultural practices, which further led to the establishment of healthy, uniform stands.
2. Integrated control of locusts: The following IPM programme is adopted to control the population of locusts:-
    - Locusts eggs are destroyed by adopting physical/mechanical methods like ploughing or flooding
    - Nymphs of Locusts are managed either by direct spraying or by barrier spraying or by adopting techniques like baiting, trenching or burning
    - Locust repellents like neem-oil (which is ecological, economical as well as harmless to environment) are sprayed on crop at the time of swarming.
    - Biological techniques are also adopted to control locust

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Check Your Progress

7. Why it is important for farmer to adopt insect pest control measures?
8. What do you understand by cultural control of pests?
9. What is a trap crop?
10. Give few examples where handpicking technique can be employed effectively.
11. Why temperature control method is considered as a useful pest control method?

3.4 INSECTS OF MEDICINAL AND VETERINARY IMPORTANCE

Arthropods include many species of medical or veterinary importance. Among them, several are responsible for the transmission of some dangerous diseases for humans, such as malaria, Chagas disease, leishmaniasis, African trypanosomiasis, lymphatic filariasis, onchocerciasis, dengue, yellow fever, and Zika. These diseases have an enormous socio-economic impact in countries where they occur. Environmental changes driven by humans, with special reference to urbanization and global warming, are promoting their emergence or re-emergence in areas where they were not previously recorded. In this scenario, the fight against key arthropod parasites and vectors relies on the knowledge of their genetic, behavioural and ecological characteristics, within a global Integrated Vector Management approach requiring new tools with proven epidemiological impact, as well as interdisciplinary communication between different research fields.

1. Head Louse *(Pediculus humanus)*

- Human lice are ubiquitous i.e., widespread. The habitat of the human louse is solely on the human body or in the clothes. They fail to survive anywhere else as they cannot survive away from the host for a few days.
- Human lice are more prevalent in unhygienic areas where people change or wash their clothing infrequently and/or are unclean themselves (Milne and Milne 1980).
- Lice are obligate ectoparasites; they feed on blood of human.
- They possess especially designed mouth parts for piercing the skin of humans as well as for retrieving the blood.
- *Pediculus humanus* is a small insect having a large abdomen.
- The legs of the *Pediculus humanus* are equipped with sharp claws for holding onto hair and clothing fibres.
- The head of the head louse is somewhat narrower than the body.
- They lack wings like most insects

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- They possess piercing mouthparts for digging into the skin and draining out the blood.
- *Pediculus humanus capitis*, is approximately 1-2 mm long, whereas the body louse, *Pediculus humanus humanus,* is usually slightly larger, having a size of 2-3.5 mm.
- The "nits," or eggs, of the head louse are approximately 1 mm long and about half as wide.
- The young lice are often referred to as "red backs," as they become red in colour due to feeding blood.
- They turn to a grey color, after the blood is digested.
- The female lice lay their eggs, which are referred to as nits, singly on the hairs of the host (if they are head lice) or attached to clothing in case of body lice.
- The nits will hatch into nymphs in a time span of eight days.
- The nymphs also suck blood and mature in eight to sixteen days.
- Each adult female body louse produces between two and three hundred nits in her lifetime
- A single female head louse produces between eighty and one-hundred.
- Blood is sucked by the pumping action of pharynx.
- Adults as well as young ones of both the sexes feed on blood.
- The mouthparts are arranged in the form of fine stylets which, except when feeding, are withdrawn within the head.
- Blood is obtained by means of the stabber which is thrust out and then slowly pushed beyond the flesh.
- A salivary secretion is also injected which prevents the coagulation of the host's blood
- This helps the insect to suck in blood without forming the clots.
- The adults can feed on up to one milligram of blood at a time.
- The adults cannot survive for long without host. Hence, they prefer to take smaller quantities at frequent intervals.
- However, head louse can survive starvation for approximately three days at 30°C and five days at 24°C.
- On taking a very large meal, blood oozed out from the anus.
- Sometimes, overfeeding leads to gut rupturing.
- Adults are capable of fairly rapid active movement.
- They have been recorded as moving at a rate of 9 inches per minute; but they never move in straight lines.

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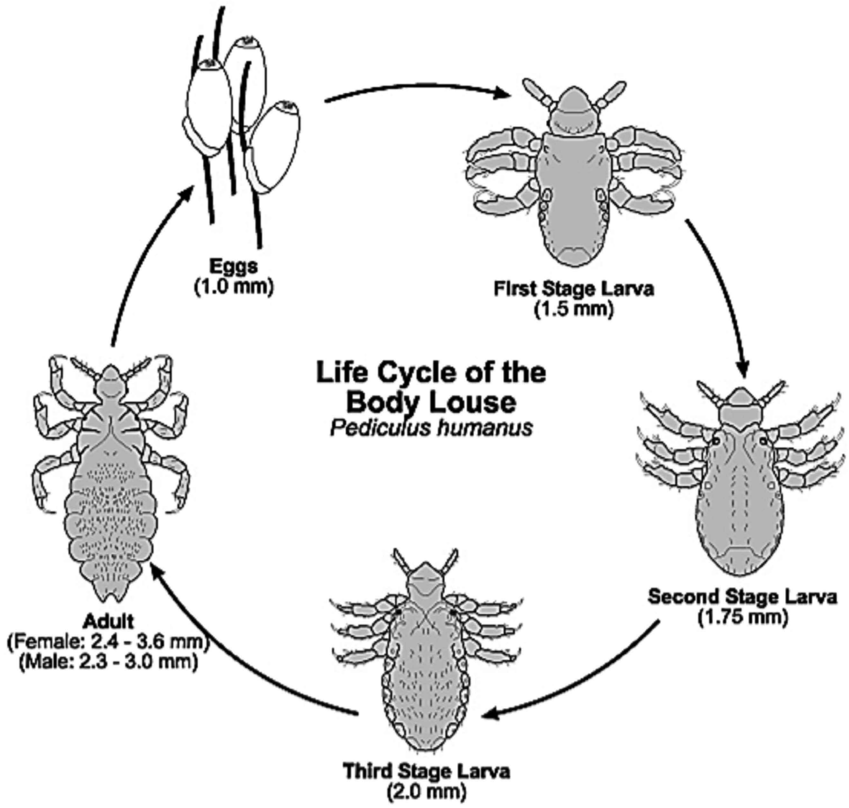

Fig. 3.32 *Life Cycle of Pediculus humanus*

Figure 3.32 is depicting the generalized life cycle of *Pediculus humanus*.

Head louse is known to cause the following diseases:

a. **Epidemic Typhus:** The reservoir host of this disease are sheep and goats. Epidemic typhus is caused by a PPLO, *Ricketsia prowazeki***,** which proliferates/increases in the gut of lice. Spores are released via faeces within 5 days of infection and can remain viable for up to four months in the dry conditions. *Ricketsia prowazeki* enters into the human system via contact with blood, wounds, conjunctive or by inhalation into lungs. The disease fatality rate is almost 100%.

b. **Trench Fever:** Trench fever is caused by *Ricketsia quintana***.** This disease was prominent among soldiers during the World War II. Spores are released via faeces within 5 days of infection and can remain viable for up to four months in the dry conditions. *Ricketsia quintana* enters into the human system via contact with blood, wounds, and conjunctive or by inhalation into lungs.

c. **Relapsing Fever:** Relapsing fever is transmitted via spirochaet, *Borrelia recurrentis*. This breeds in the haemolymph of the louse and escapes when the louse is crushed or dies due to the parasitic infection. It gets into the human blood via wounds or scratches. This disease was prominent during the World War I and II.

d. **Vagabond Disease:** The common symptoms of this disease are itching, rashes and discoloration of the skin. Such symptoms occur due to the allergic reaction to the bites and blood sucking by lice.

Control of head louse can be done as follows:

- Cleanliness and maintaining personal hygiene eradicate lice.
- Washing the hairs with anti-lice shampoo such as malathion (Lycil) and Mediker shampoo.
- Application of kerosene mixed with olive oil in equal ratio on the head kills lice.
- Lindane ointment, malathion (Lycil) and Mediker shampoo (also contains malathion) or any insecticide mixed with oil kills all lice on head.
- The application has to be repeated every week to kill nymphs emerging from eggs.
- Body lice can be controlled by steaming or boiling of clothes and bedding or rinsing clothes in weak insecticide solution.

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2. The Crab Louse *(Phthirus pubis)*

- Crab louse (*Phthirus pubis*) is limited to the pubic region of human beings.
- Thoracic region of crab louse is very broad and abdomen is narrower when compared to the thorax.
- Crab louse is five-segmented.
- It bears small paired appendages.
- Crab louse are very sluggish lice.
- Fecundity is approximately 50 eggs/female.
- The eggs hatch in a time span of 7-8 days.
- Nymphs generally take 27-33 days to develop into adults.
- Nymphs are very similar to the human louse.
- Body of crab louse is much broader when compared to its length.
- Legs appear to attach to the edge of the somewhat flattened body rather than to the underside.
- Crab louse moves very slowly.
- Crab louse are named so due to their crab like motion.
- As the name suggests, it infests hairs of pubic region as well pre-anal region of both sexes.

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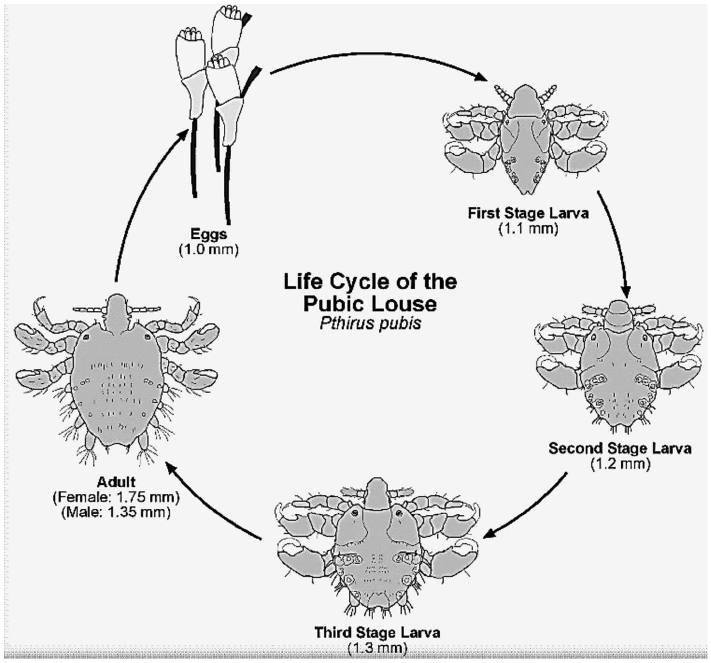

Fig. 3.33 *Life Cycle of Pthirus pubis*

Figure 3.33 is depicting the life cycle of *Pthirus pubis*.

- Current worldwide prevalence of crab louse is estimated to be around 2% of the human population, however, accurate numbers are difficult to report as crab louse infestations are not considered a serious medical condition by health authorities. Most of the cases can be easily self-managed.
- Maintenance of hygiene has played a crucial role in reducing the world-wide population of crab louse.
- They are essentially found on the pubic region, however, infestation can also be seen on coarse hair elsewhere on the body (for instance: eyebrows, eyelashes, beard, moustache, chest, armpits, etc.).
- Crab louse do not generally occur on the finer hair of the scalp.
- Crab lice attach to pubic hair that is thicker than other body hair as their claws are adapted to the specific diameter of pubic hair and other thick hairs of the body.
- Crab louse infestations (pthiriasis) generally occurs via sexual contact and are most common in adults.
- The crab louse can travel up to 25 cm (10 in) on the body.
- Crab louse infestation is found worldwide and occurs in all races and ethnic groups and in all socio-economic levels.
- They can also be transmitted by close personal contact or contact with articles such as clothing, bed linen, and towels that have been used by an infected person.
- Crab louse present on the head or eyelashes of children might indicate sexual exposure or abuse.

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- The main symptom of infestation with crab lice is itching, usually in the pubic-hair area, resulting from hypersensitivity to louse saliva, which can become stronger over two or more weeks following initial infestation.
- In some infestations, a characteristic grey-blue or slate coloration appears (*maculae caeruleae*) at the feeding site, which may last for several days.
- Crab lice are not known to transmit disease; however, secondary bacterial infection can occur from scratching of the skin.
- Crab louse infestation can be diagnosed by identifying the presence of active stages of the louse, as well as of eggs (nits) on the pubic hair and other hairs of the body.
- When infestation is diagnosed, other family members and contact persons should also be examined.
- A magnifying glass or dermoscope could be used for better identification.

To control crab louse following measures can be adopted:

- All sexual contacts of the infected person should be examined carefully.
- All those who are infested should be treated.
- Sexual contact between the infested person(s) and their sexual partner(s) should be avoided until all have been examined, treated as necessary, and revaluated to rule out persistent infestation.
- Washing all the clothes used by the infected person with hot water at least 130°F.
- Do not share clothing, bedding, and towels used by an infected person.
- Avoid using fumigant sprays or fogs as they can be toxic if inhaled through skin.
- Persons with pubic lice should be examined and treated for any other Sexually Transmitted Diseases (STDs) that may be present.

3. Fleas

- Fleas are small wingless insects.
- The length of the flea is approximately 2-3 mm long.
- The fleas are reddish-brown in colour.
- The fleas are highly sclerotised, having laterally compressed bodies.
- Antennae of the fleas are short, stout, pectinate or clubbed and concealed in a groove.
- Mouth parts of the fleas are modified for piercing and sucking action.
- Legs of the fleas are adapted for clinging with curved claws.
- Hind leg is longer and modified for jumping.
- Body of the flea's bears backwardly directed spines that help them to move through the hairs of the hosts.
- The abdomen of the male is directed upwards at the apex and flat.

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- Apical part of the abdominal region bears a coiled cirrus organ which serve as the copulatory organ of the male.
- The abdomen of the female is directed straight backwards and carries a small pouch-like structure known as spermatheca.
- Spermatheca bears sperms after copulating with the male.
- Fleas breed in dark and secluded places having high moisture contents like dusty floors, under carpets, rat burrows, granaries, chicken houses as well as godowns.
- Female lays approximately 300-400 eggs in its lifetime.
- The incubation period varies from 2-3 days (maximum 12 days).
- Larvae is yellowish-brown in colour, caterpillar-like, 13-segmented, hairy
- Larvae move actively, feeding on dead and decaying organic matter as well as on faeces of the adult fleas.
- Larva is approximately 4 mm in length and lack eyes, antennae as well as legs.
- Larvae bears long bristles on the body, which also help the fleas in locomotion.
- There are 3 instars and larval period ranges between 7 to 10 days.
- Pupation of the fleas takes place in a very tough, dull whitish cocoon that is concealed in dust particles.
- Pupal period is approximately seven days.
- Pupa may hibernate for up to a period of one year.
- The entire life cycle of the fleas is completed in about 20 days under favourable conditions.
- After emergence, adults hop on to the passing rats or other hosts and start sucking blood.
- Rats usually sucks in more blood than necessary.
- A lot of undigested blood passes along with faeces that form food for the larvae.
- An adult can jump up to 8 inches high and 13 inches in length.
- Longevity of the adult is approximately two years.
- It can tolerate/resist starvation up to a period of six months.
- There are about 200 species of fleas in India.

A few well known common species are Human flea *(Pulex irritans),* Rat flea *(Xenopsylla cheopis,* Dog and Cat flea *(Ctenocephalides canis,* Combed Rat flea *(Nosopsylla or Ceratophyllus* sp.*),* Broken-headed mouse flea *(Leptopsylla segnis)* and Rat flea *(Stivalius ahale).*

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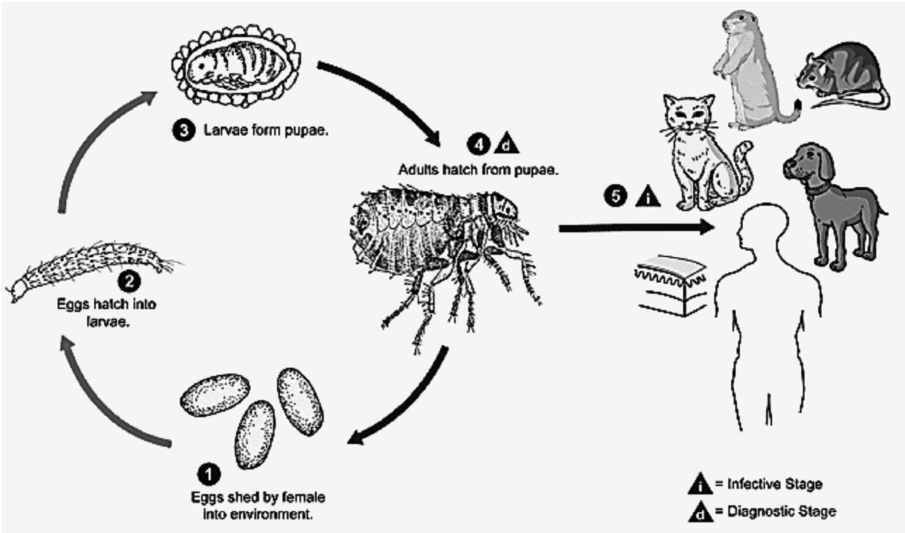

Fig. 3.34 *Life Cycle of Flea*

Disease Transmission

Fleas majorly transmit plague that is caused by the safety pin bacillus called ***Yersinia pestis*** or ***Pasturella pestis.*** Plague is caused in man and in rats equally and produces three types of symptoms in man.

a. **Bubonic Plague.** The bacillus infects lymphatic system, leading to swelling and pain in the lymph glands, however, no fever occurs. Rats also suffer from similar kind of symptoms.

b. **Septicaemic Plague.** Septicaemic plague spreads to the blood vascular system causing fever. It causes headache as well as pain in the back. Sudden chilliness, redness of eyes, rapid pulse, thick speech and high fever are other symptoms. In the case of prolonged illness, spleen enlarges in size and becomes brick-red in colour and liver is also enlarged. Coma and death are quite possible.

c. **Pneumonic Plague.** Pneumonic plague multiplies in the lungs and pleural cavity causing pneumonia-like symptoms. A Yellowish colour fluid fills the lungs and pleural cavity, leading to excessive coughing as well as heavy breathing. Infection can spread directly from man to man via droplets which are released during coughing. Pneumonic plague is one of the most dangerous kind of plague as it spreads rapidly by droplet infection, chiefly in areas having high population density and leads to quick deaths. Figure 3.35 is depicting the transmission of disease by fleas

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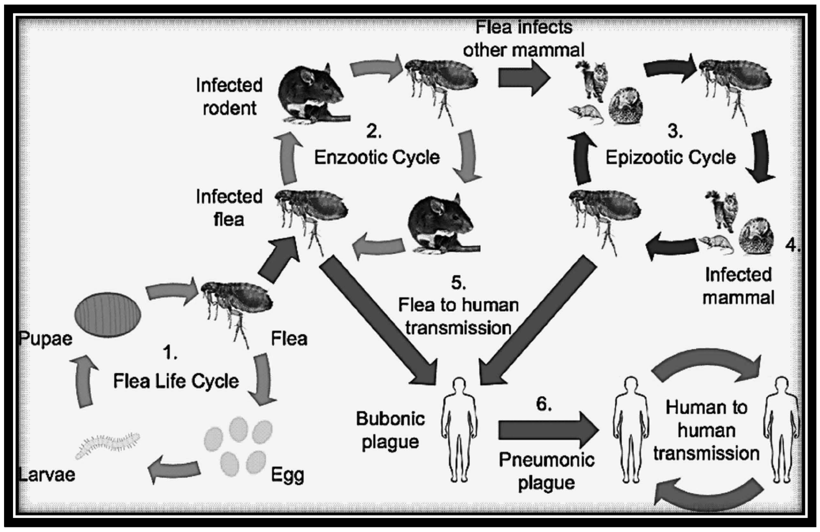

Fig.3.35 *Transmission of Disease by Fleas*

Mode of Infection

- Whenever, a flea sucks in blood from a rat infected with plague, it gets bacillus into the crop region along with the blood meal.
- The bacilli get attached to the spines of proventriculus and form mucilaginous colonies there, multiplying very fast, blocking the passage of blood into the intestine.
- Such fleas are referred to as *blocked fleas* that always remain hungry as the blood does not pass into the intestine.
- Hence, they keep biting and sucking blood constantly but regurgitating it in the same wound as the stomach is already full of blood and bacilli.
- In doing so, they keep transmitting bacilli from their stomach to the new hosts.
- Blocked fleas can survive up to 40 days and transmit disease continuously.

4. Mosquitoes

- Mosquitoes are small approximately 15 mm in length.
- It is two-winged insects.
- Mosquitoes can be differentiated from other flies due to the presence of following characteristics: a long proboscis projecting in forward direction from the head; the presence of scales on the wing veins; presence of fringe of scales along the posterior margin of the wing; and a characteristic wing venation, the second, fourth and fifth longitudinal veins being branched (Goma, 1966).
- Males and females can be differentiated by the different structure of the antennae.
- In males, plumose like antennae are present

- In females, antennae bears only a few short hairs.
- Genera and species identification can be performed by standard entomological aspects such as exterior, arrangement of eggs, habitus etc.
- Further and newer techniques include biochemical techniques such as enzyme electrophoresis and gas chromatography of cuticular carbons, and DNA probes.
- Mosquitoes are holometabolous insects showing all the four different stages i.e., egg, larvae, pupa and adult.
- Most of the common and important mosquitoes act as transmitters of pathogens for animal as well as man belong to four different genera namely: *Anopheles, Culex, Mansonia* and *Aedes.*
- Mosquitoes bears sensory organs in their antennae to recognise host and oviposition sites
- The Johnston's organ in the basic segment by which males recognise wing beats of the females.

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Figure 3.36 is showing a generalized life cycle of mosquito showing different stages, i.e., egg, larva, pupa and adult.

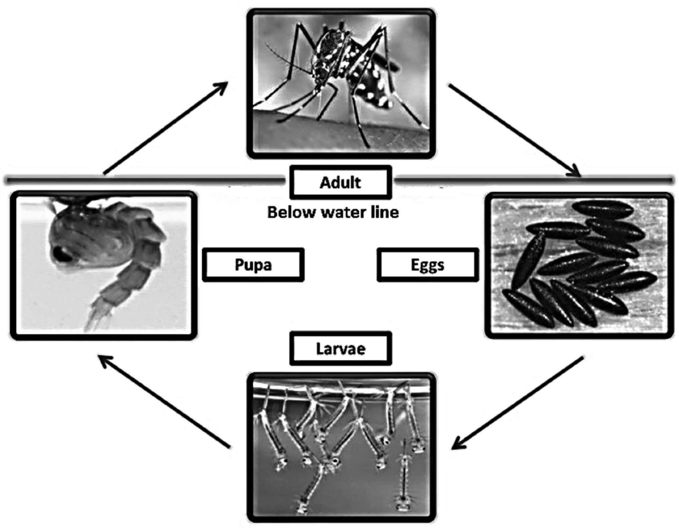

Fig. 3.36 *Generalized Life Cycle of Mosquito*

Identification Characters of Mosquito

- Males have rudimentary maxillae and mandibles; hence they fail to suck blood but can easily suck fluids and nectar from flowers.
- Males also possess very bushy whorl plumose antennae and tip of abdomen with typical male genitalia.
- Females have short hairs on the antennae and needle-like maxillae and mandibles for piercing the skin of host for sucking blood.
- Other characteristics are summarized below according to the species.

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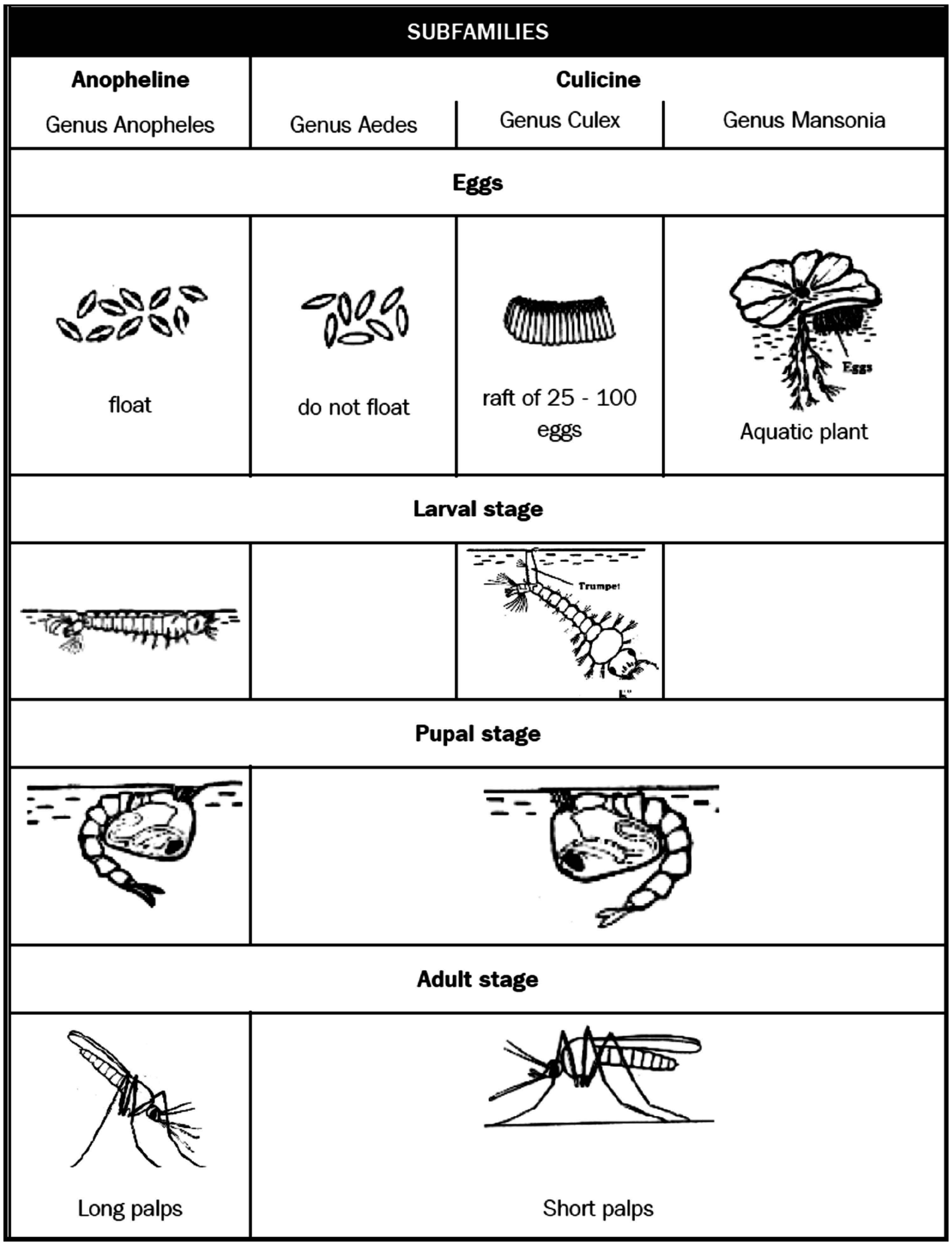

Fig. 3.37 *Different Stages of Life Cycle of Mosquito*

Mosquito Control

It is difficult to achieve successful mosquito control measures as they develop resistance against insecticides very quickly. Moreover, they are able to inhabit a variety of environmental conditions. Still, some measures have been adopted to reduce mosquito populations.

(A) Personal Preventive Measures

- Use of effective mosquito repellent such as citronella oil, dimethylphthalate, odomos cream or pyrethrum cream
- Use of mosquito nets
- Frequent use of mosquito repelling fumigants

(B) Anti-larval Measures

- Removal of breeding places for mosquito such as pots, old tyres, tins and other containers
- Water storage tanks, coolers should be cleaned and treated periodically
- Do not allow water to be stagnant
- Biological control of larvae and pupae in ponds has been achieved by releasing larvivorous fishes, such as the native *Gambusia. These fish actively feeds on the larvae of mosquito*

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(C) Anti-adult Measures

- Spraying insecticide
- UV electrocuting traps should be used to attract and kill adults.
- Destruction of tall grasses and bushes which serves as local breeding ground for adults.
- Aerial sprays of pyrethrum, carbaryl, carbofuran, arprocarb mixed with mineral oil are still effective in killing adults.

(a) Female Anophele*s* mosquito causes Malaria. Four different species of *Plasmodium* namely *P. vivax, P. falciparum, P.ovale* and *P. malariae* are known to cause malaria in human population.

(b) Culex Mosquito causes Filariasis or elephantiasis.

(c) Female *Aedes aegypti* causes Dengue Fever**.**The virus is transmitted by a female mosquito of *Aedes aegypti* and *A. albopictus* species. These mosquitoes typically lay eggs near standing water in containers that hold water, like buckets, bowls, animal dishes, flower pots, and vases. *Aedes* mosquitoes prefer to bite people, and stay both indoors as well as outdoors near people. Mosquitoes become infected when they bite a person infected with the virus. Infected mosquitoes can then spread the virus to other people through bites.

(d) *Aedes aegypti* and *Aedes albopictus* mosquitoes' spreads Chikungunya virus**.** Chikungunya virus is most often spread to people by *Aedes aegypti* and *Aedes albopictus* mosquitoes. These are the same mosquitoes that transmit dengue virus. They bite during the day and at night. During the first week of infection, chikungunya virus can be found in an infected person's blood and passed from that person to a mosquito through mosquito bites. An infected mosquito can then spread the virus to other people.

(e) *Aedes aegypti* and *Aedes albopictus* mosquitoes' spreads Zika Virus**.** Zika virus is spread by a similar species responsible for dengue and chikungunya disease. Zika is spread majorly by the bite of an infected *Aedes* species mosquito (*Ae. aegypti* and *Ae. albopictus*). Zika can be passed from a pregnant woman to her foetus. Infection during pregnancy can cause certain birth defects. This causes the small head and brain size in newborns, resulting in neurological defects leading to death. Guillain-Barre syndrome is also another life-long condition caused by the Zika virus.

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(f) Yellow fever is commonly found in both tropical and subtropical areas of Africa and South America. Its name 'yellow' comes from its common symptom known as jaundice. Yellow fever virus is basically an RNA virus that belongs to the genus *Flavivirus*. This virus is transmitted to people via bite of infected *Aedes* or *Haemagogus* species mosquitoes.

(g) Japanese Encephalitis (JE) virus, a flavivirus, is closely related to West Nile and St. Louis encephalitis viruses. JE virus is transmitted to humans through the bite of infected *Culex* species mosquitoes, specifically *Culex tritaeniorhynchus*. JE virus is maintained in a cycle between mosquitoes and vertebrate hosts. Pigs and birds are the major vertebrate hosts. Humans are basically incidental or dead-end hosts, as they generally do not develop high concentrations of this virus in their bloodstreams to infect feeding mosquitoes.

There are more than 3000 species of mosquitoes in the world which are virtually distributed everywhere except in Iceland and poles. The Table 3.5 below lists a few mosquito species which are responsible for transmitting deadly human diseases:

Table 3.5 *Mosquito Species and Diseases Spread*

Genus	Breeding site	Place found	Disease and distribution
Anopheline mosquitoes Anophelines breed in non polluted water Biting period : NIGHT	edges of rivers, swamps, impoundments, ditches, tanks, saltwater habitats protected from wave action, rice fields, temporary rainpools, hoofprints.	Worldwide	▪ Malaria: Tropical and sub-tropical areas ▪ Bancroftian filariasis: Asia and Africa ▪ Brugian filariasis: Asia ▪ O'nyong nyong virus: Africa
Aedes mosquitoes One species lives in close association with man, in any kind of human settlement. The *A. aegypti* breeds in any small water collection. Aedes spp. are primarily forest mosquitoes. Biting period : DAY	Tin cans, plastics, car tyres, gutters, ornamental ponds, tanks, jars, any type of container, waste disposal areas, tree holes.	Worldwide	▪ Yellow fever: Africa and Americas ▪ Dengue: Africa, Americas, Asia ▪ Dengue Haemorrhagic fever: Americas, Asia ▪ Bancroftian filariasis: Pacific ▪ Other arbovirus: Africa, Americas, Asia
Culex mosquitoes *C. quinquefasciatus* breed in any dirty water in urban and rural areas. Other species are also very common in rice fields in Asia. Biting period : NIGHT	*C. quinquefasciatus* Waste water ditches, latrines, septic pits, cesspools, drains, waste disposal.	Worldwide	▪ Bancroftian filariasis: Most tropical areas ▪ Encephalitis virus: Africa, Americas, Asia, Europe

Mansonia mosquitoes Mainly associated with aquatic plants, in rural areas where irrigation canals occur. Biting period : NIGHT It is a vicious biter	Ditches, ponds, irrigation canals, swamps.	Essentially tropical Worldwide	▪ Brugian filariasis: Asia ▪ Other arbovirus: Rare in Africa and Americas

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6. Sand Flies

- Sand flies are small insects.
- The length of the sandflies is approximately 1.2-3.7 mm (Perfiliev, 1968).
- Head, thorax, abdomen and appendages are covered with hairs which give a "fluffy" appearance to the sand flies.
- The palps reach beyond the proboscis region and are nearly folded in two.
- The wings are raised above the body.
- The apex of the wings is directed posterior and lateral.
- Legs are long and slender in structure (Perfiliev, 1968).
- Sand flies which are disturbed on a wall do not usually fly, however, they jump away, rising to the ceiling.
- This jumping behaviour, the raised wings and the "fluffiness" are reported to be so characteristic that recognition of a live sand fly and distinguishing it from other small insects is possible (Perfiliev, 1968).
- Females and males of the sand flies are easily distinguishable.
- In females, the end of the abdomen appears blunt.
- The abdomen is narrow immediately after hatching, however, it gets inflated and reddish in colour after the first blood meal.
- The color of the abdomen changes brown to black after digestion of the blood and it becomes characteristically thicker with a yellowish shade during egg development.
- The male abdomen resembles that of unfed females or even thinner and ends in paired appendages, appearing like small spines to the naked eye (Perfiliev, 1968).
- Besides anatomical structures, techniques like isoenzyme electrophoresis, gas chromatography, monoclonal antibodies and DNA probes are used for species identification and differentiation.

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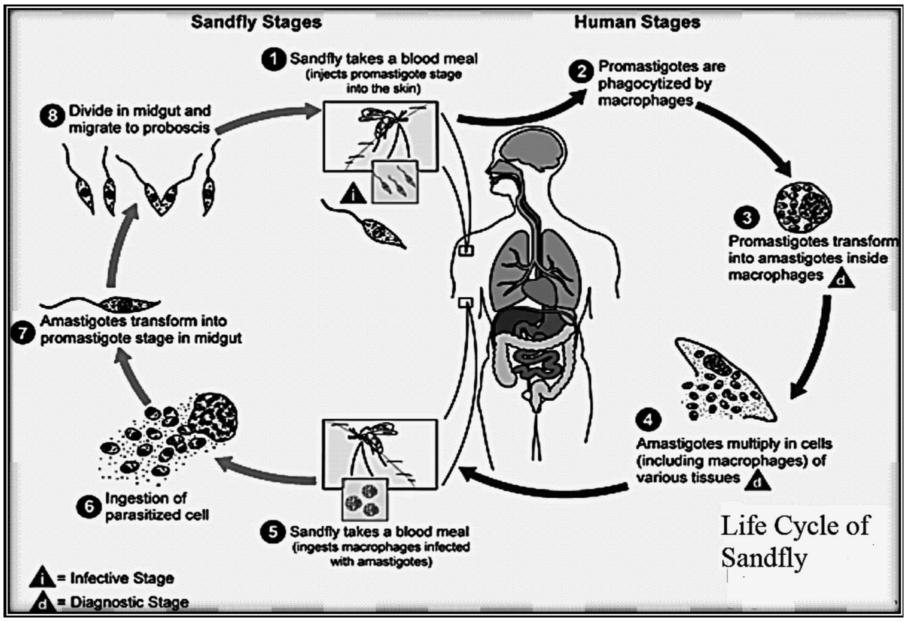

Fig. 3.38 *Life Cycle of Sandfly*

Following stages of the life cycle of sandfly are shown in the figure 3.38.

1. Female phlebotomine sand flies transmit the infective stage, i.e., promastigotes from their proboscis during blood meals.
2. Promastigotes that reach the puncture wound are phagocytized by macrophages.
3. Promastigotes are transformed inside these cells into the tissue stage of the parasite i.e., amastigotes.
4. Amastigotes multiplies to infect other mononuclear phagocytic cells.
5. and 6) A lot of factors like parasite, host decides whether the infection will be cutaneous or visceral leishmaniasis. Sand flies gets the infection by ingesting infected cells during blood meals.
7. In sand flies, amastigotes transform into promastigotes, develop in the gut.
8. (in the hindgut for leishmanial organisms in the *Viannia* subgenus; in the midgut for organisms in the *Leishmania* subgenus) and migrate to the proboscis.

The disease caused by sandflies is known as Leishmaniasis (***Visceral leishmaniasis*** *and* ***Cutaneous leishmaniasis***).

There are about 33 species of sand flies in India, some of which are known to transmit diseases. The table 3.6 below lists some sand fly species which are known to transmit deadly diseases.

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Table 3.6 Species of Sand Fly and Transmitted Disease

Sandfly species	Disease name	Causative organism	Distribution
Phlebotomus argentipes	Kala-azar,	*Leishmania donovani*	NE India, TN
P. sergenti; P. papatasii	Oriental Sore	*Leishmania tropica*	C and N India
Phlebotomus papatasii	Sandfly fever	Virus	Whole India
P. intermedius	Espundia (naso-Pharyngeal leish-maniasis)	*Leishmania braziliensis*	S. America
P. varrucarum	Carrion's disease	*Bartonella bacilliformis*	S. America

Sand Fly Control

- Spraying the houses with malathion, endosulfan, carbaryl etc. kills the sand fly adults and other stages.
- Maintaining cleanliness in houses and surroundings and
- Plastering of cracks and crevices also reduces adult population.
- Spraying of breeding places with insecticides is an effective control measure.
- It is difficult to control larval population as they burrow deep into the soil, however, treating the garbage dumps with insecticides helps in controlling the population.

7. Housefly

House fly is a larger insect, approximately 6-7 mm long, greyish in colour with blackish markings on the body. It has two wings with a wing span of 13-15 mm and posterior wings being modified in a pair of balancers or halteres. Figure 3.39 is depicting the life cycle of housefly.

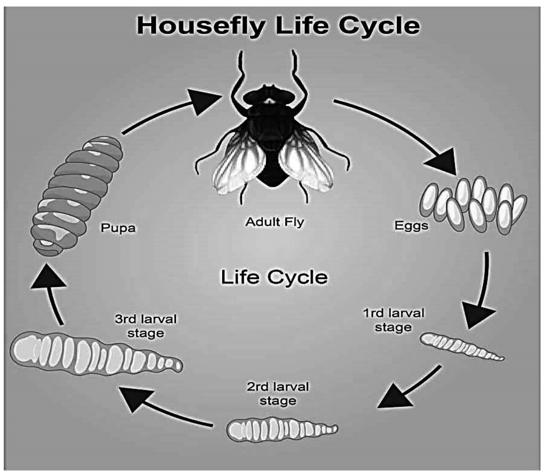

Fig. 3.39 *Life cycle of Housefly*

The table 3.7 below list the disease transmitted by house fly.

Table 3.7 *Disease Transmitted by House Fly*

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Disease	Causative organism
1. Cholera	1. *Vibrio cholerae*
2. Typhoid	2. *Salmonella typhi*
3. Paratyphoid	3. *Salmonella paratyphi*
4. Amoebic dysentery	4. *Entamoeba histolytica*
5. Bacillary dysentery	5. *Shigella dysenteryi*
6. Poliomyelitis	6. *Polio virus*
7. Trachoma eye disease	7. *Virus*
8. Eggs of many species of Parasitic worms	8. Cestodes and nematodes

Control of House Flies

- Removal of breeding places: Maintenance of cleanliness is an effective method to bring down population of house fly.
- Treatment of breeding places: Cover the breeding grounds with a layer of insecticide dust such as 5% DDT to prevent flies to feed and lay eggs.
- Adults can be killed by spraying insecticide such as malathion, Baygon, , lindane, carbaryl or endosulfan
- UV emitting electrocuting trap are quite effective in attracting and killing adults
- Biological control: *Spalangia,* has been found to be very effective in destroying pupae of houseflies.

8. Tsetse Fly

- Tsetse fly belongs to genus ***Glossina*** of family Glossinidae and is pronounced **tse-tse** or **teet-see** or **set-see**.
- Tsetse are large biting flies which are found in Africa.
- Tsetse flies suck blood of vertebrates and transmit numerous protozoan diseases.
- Tsetse flies can be differentiated from other flies as they fold their wings completely while resting in such a way that one wing rests directly on top of the other.
- The color of the adults varies from yellowish to brownish in colour.
- Adult possess a piercing proboscis as well as a hatchet-shaped cell in the centre of each wing.
- The arista of the third antennal segment has branched setae.
- Larvae of tsetse flies breathe via a pair of posterior spiracles
- Third instar larvae respire via a pair of lateral lobes, which comprises of three air chambers and open to outside via numerous spiracles.

- Female tsetse flies are viviparous
- Female tsetse flies retains a single egg that develops to the third larval stage before being deposited.
- The egg within the uterus hatches in a time span of 3–4 days
- The egg hatches to form first instar larva that obtains nourishment from secretions of a pair of uterine glands from the mother.
- The third instar larvae are deposited in soil.
- Inside the soil, they form burrows and keep on feeding and pupate for 4–5 weeks.
- The young adult emerges from the pupa and both sexes suck blood.
- Males remains infertile for several days after emergence.
- On the contrary, females are ready to copulate two to three days after emergence.
- The first larval offspring is deposited about 9–12 days after the female emerges.
- Tsetse flies females live up to fourteen weeks.
- Males live for approximately six weeks.
- Tsetse flies comprises of around thirty-four species and sub-species that are placed in a single genus known as ***Glossina***.
- A few species of tsetse flies transmit trypanosome species that cause trypanosomiasis or **sleeping sickness** in humans caused by T***rypanosoma brucei gambiense*** and ***T. brucei rhodesiense***.
- In animals, they transmit **nagana**, in cattle, horses, pigs and antelopes which is caused by ***Trypanosoma brucei brucei, T. congolense*** and ***T. simiae*** and **surra** in horses and pigs caused by ***Trypanosoma suis.*** Tsetse transmits trypanosomes in two ways:
- Mechanical transmission of the disease involves direct transmission of trypanosomes taken from an infected host into an uninfected host. In this, tsetse fly feeds on an infected host and acquires trypanosomes in the blood meal and then, if within a short period it feeds on an uninfected host and regurgitates infected blood and saliva into the tissue of uninfected animal, it has transmitted the protozoans.
- Biological transmission of the disease requires a period of incubation of the trypanosomes within the tsetse stomach where the protozoans reproduce via several generations to become infective stage. Tsetse infected by trypanosomes are thought to remain infected for the remainder of their lives.

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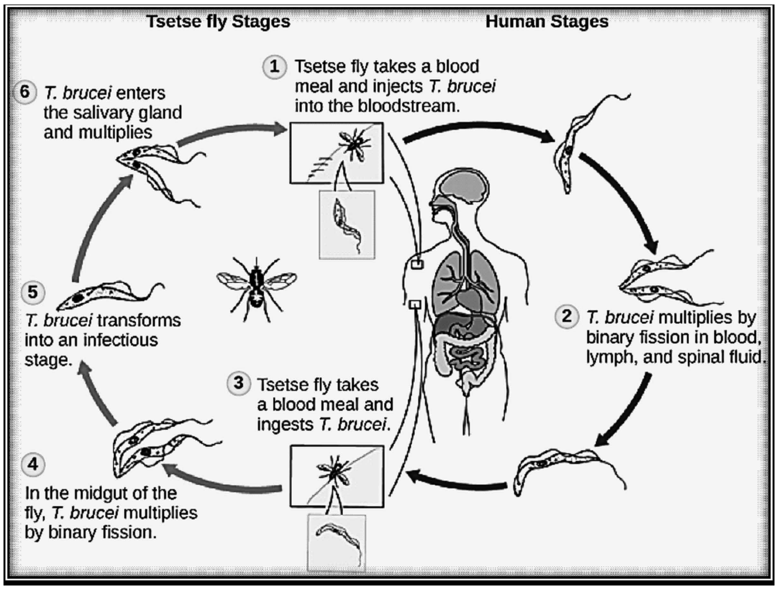

Fig. 3.40 *Life Cycle of Tsetse Fly*

Figure 3.40 is depicting the life cycle of Tsetse fly.

9. Triatoma/Kissing Bugs

- Kissing bugs are members of the Order Heteroptera, or true bugs, and the family Reduviidae.
- They have a distinct narrow and elongated head.
- Body color varies from dark brown to black with orange to red to yellow markings on the outer edges of the body when viewed from above.
- Adults can be 1 to 1.5 inches in length.
- All members of the family Reduviidae can bite, and they all have a relatively short 3-segmented beak that can fit in a small groove between their front legs.
- Kissing bugs feed on warm blooded animals and can transmit the parasite *Trypanosoma cruzi* that is the causative agent of Chagas disease.
- This disease is found in the US and throughout central and South America.
- Parasite transmission does not occur via the action of feeding, it occurs when insect fecal matter enters a wound, like the site of the insect bite.
- Transmission can also occur through mucus membranes of the nose or mouth.
- Dogs can also get infected by eating kissing bugs.
- The life cycle includes an egg stage, several nymphal stages wherein the nymphs look like wingless smaller versions of the adults, and an adult stage.
- Kissing bugs have five nymphal stages and there is no intermediate pupal stage.
- Adult kissing bugs are good fliers and fly at night to find mates and animals for blood feeding.
- Additionally, they are attracted to lights during these night flights.

Kissing bugs causes Chagas disease also called as American Trypanosomiasis caused by *Trypanosoma cruzi.*

The table 3.8 below lists other insect vector along with their habit, habitat, distribution and the disease transmitted**.**

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Table 3.8 *Insect Vector Habit, Habitate and Transmitted Disease*

Vector (genus)	*Particularity*	*Breeding sites and habits*	*Disease and distribution*
Tabanid or Horsefly *1. Chrysops*	They are very robust Length; 6 to 10mm	Only the female feeds on any animal. She lays 100 to 1000 eggs according to species. They breed in moist and wet ground.	■ *Loa loa* filariasis: West and Central Africa
Tsetse fly Glossina *Mortisans group* (savannah flies) *Palpalis group* (river bank flies)	Very long proboscis wide wings 9 to 25mm in length	Both males and females suck blood. Tsetse flies are viviparous. They deposit their larvae in damp ground and arid areas.	■ Sleeping sickness: Africa
Sandfly *Phlebotominae*	Less than 3mm long Very long legs	The females only are blood-sucking at night. They are located in the tropics and subtropical areas south of Europe. They breed in moist and wet ground.	■ Cutaneous and visceral (Kala Azar) Leishmaniasis occur in Sudan, Latin Americas, India, Asia, Middle East, and Southern Europe
Bedbug *Cimex spp.* Reduviid bugs	7mm long brownish insects flat and oval body	They lives in temperate and tropical zones. They are active only at night where they feed on humans and animals.	■ Bedbugs cause nuisance such as itchiness: Worldwide ■ Chagas disease is transmitted by triatomine bugs in South and Central Americas, and in some parts of Caribbean
Blackfly *Simuliidae*	Small insect, 1 to 6mm in length	They bite during the day. Only the female sucks the blood of animals and humans. They breed and live in all kinds of unpolluted water, vectors in Africa breed only in fast flowing oxygenated streams or rivers. They have a worldwide distribution.	■ Onchocerciasis or river blindness: Africa, and some parts of Latin America

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Vector (genus)	Particularity	Breeding sites and habits	Disease and distribution
Cockroach	5 to 73mm in length two pairs of wings flattened appearance Yellow-brown to dark colour	These insect are very agile and fast and live in colonies. They have a preference for man-made structures where it is warm. In the tropics they may live and breed outdoors. Latrines may be infested in a refugee camp. They are particularly active at night.	▪ Cockroaches act as mechanical vectors and may transmit diarrhoeal diseases, typhoid fever, dysentery, viral diseases: Worldwide

3.4.1 Insects of Veterinary Importance

The goal of this topic is to introduce students to the fascinating world of arthropod pests that impact the health and well-being of domesticated animals. It lays emphasis on understanding the remarkable biology of blood-feeding arthropods and the diseases that they transmit to companion and livestock animals. The insects of veterinary importance are as follows:

1. Pest of Cattle

(a) Biting Midges

Biting midges, is also commonly known as "no-see-ums" or "punkies". They are a group of small blood-feeding flies belonging to the genus *Culicoides*. Biting midges can transmit severe animal pathogens like Blue Tongue Virus (BTV), Epizootic Hemorrhagic Disease Virus (EHDV), as well as African Horse Sickness Virus (AHSV). BTV and EHDV are widespread viruses that affect ruminant animals like cattle, sheep, and deer. Recent outbreaks of BTV in Europe and EHDV in the United States have resulted in considerable animal mortality as well as serious economic impacts to cattle or deer producers, respectively. AHSV is majorly limited to sub-Saharan Africa where it affects equids causing high mortality in horses as well as donkeys, with zebras serving as a reservoir of the virus. Biting midges usually develop in organically enriched moist to semi-aquatic habitats like wet animal manure, deep leaf litter, tree-holes, or manure-polluted effluent emanating from confined animal facilities. Majority of the biting midge species become active toward the dusk and may bite throughout the night. It is only the female biting midges that feed on blood, using bladed mouthparts to cut into the host skin until blood flows from torn capillaries beneath the skin surface of the host. Biting sites on the host are often determined by the species of biting midge, with many midge species biting the host on the belly while other species prefer to attack near the head or ears.

(b) Face Flies

Musca autumnalis are commonly known as face flies. They are pests of pastured livestock animals like beef cattle, heifers, and horses. Female adults of face flies, use their sponging proboscis with teeth to feed as well as scrape at wounds and around moist-mucus membranes of an animal's face. The pain which occurs due to this feeding habit makes the livestock nervous, and then they are forced to spend their growing days in shade in order to avoid feeding by pests. A feeding face flies can also transmit pathogens like *Moraxella* species as well as *Brucella abortus* which can cause pink eye, bovine viral diarrhea virus, as well as *Thelazia* eye worms. Adult face flies lay their characteristic eggs having a black respiratory stalk in fresh dung and then larva emerges out of the egg. The newly emerged larva undergoes molts to form three instars. During the final instar stage, the larva migrates from the dung to a drier area and then pupates inside a white calcified puparia. It has been observed that the males of face flies emerge before the females and then both male as well as female feeds on nectar of flowering plants.

(c) Horn Fly

Horn fly is regarded as one of the major pests of cattle. Horn flies spend most part of their adult life on the body of their cattle host. They possess long bayonet-type mouthparts which is known as proboscis, containing rasping teeth which are then used to tear through the skin of cattle causing blood to pool at the skin surface. Both male as well as female sexes of the horn fly feed on the blood. Horn flies take approximately 20-30 small blood meals from their host body in a day. Cattles are generally seen with thousands of horn flies on its body. Horn flies clustered in high numbers on cattle's body can cause significant animal stress and production losses. Horn flies have been implemented as a developmental vector (carrier) for *Stephanofilaria stilesi*, a spirurid nematode that causes stephanofilariasis in cattle. Stephanofilariasis is a granular dermatitis that occurs mainly on the belly, scrotum, prepuce and udder of cattle in the western United States.

(d) Stable Fly

Stable fly is a major pest of cattle. Male as well as female adult stable flies need blood meals at regular intervals preferably from the lower body and legs of cattle. Stable flies possess long bayonet-type mouthparts which is known as proboscis, and this is used by the stable fly to tear through the skin of the animal causing blood to pool at the skin surface. These bites can be quite painful. Stable flies are more prevalent in rainy season as compared to dry summers.

(e) Cattle Grubs

Cattle grubs represents the immature or larval stages of flies like heel, warble flies or gad flies. Two species of cattle grubs affect the cattle badly. These species are: *Hypoderma lineatum*, the common cattle grub and *Hypoderma bovis*, the northern cattle grub. Both the species of cattle grubs are commonly found in Africa, Asia, Europe and North America, but mainly from 25º to 60° latitude in the Northern hemisphere. They resemble bee in their physical appearance and are 11 to 18 mm in size. Eggs remain attached to lower hairs on the animal's body, particularly the legs region. This activity frightens the host animal which reacts by running with its tail in the air, bent over the back. This behaviour is called as 'gadding'. Due to gadding behaviour, cattle fails to graze normally which ultimately leads to loss of milk production. In order to prevent flies from attacking them, cattle instead of feeding, keep standing in shady areas. Larvae hatches from the eggs approximately after four to six days and then crawl down the hair of the cattle and burrow into the skin. Larvae of the common cattle grub migrate through the animal's

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body until they reach the gullet, while northern cattle grub larvae move to the region of the spinal canal. Older larvae then spend several months migrating to the back of an infested animal. Once at the back, the larvae cut a breathing hole through the hide and develop a cyst or swelling, known as warble. Warbles are visible even to the naked eye and can be sensed by touch. After a period of six weeks fully grown larvae exit out of the breathing holes, drop to the ground and then begin burrowing into the soil to pupate. Adult flies emerge from the pupae in three to ten weeks. The entire life cycle of cattle grub takes approximately a year to complete, with eight to 11 months spent inside an animal. Cattle grubs can be controlled by the application of endectocides (macrocyclic lactones) applied either as a pour-on or by an injection.

2. Pest of Poultry

(a) Housefly

Not only to the cattle, houseflies are nuisance for birds too. It is a common pest of poultry, particularly at caged layer facilities where immature flies develop in the manure accumulating beneath confined birds. House flies have been implemented to transmit the chicken tapeworm *Choanotaenia infundibulum*. Prevalence of this tapeworm becomes greatly reduced by elevating the cages of chickens. Secondary wound myiasis cases have been recorded at times. The female house fly is attracted to the purulent wounds to feed and lay eggs. The ensuing larvae develop in the wound discharges and slow the healing process.

(b) Black Soldier Fly

The black soldier fly (*Hermetia illucens)* is a "wasp-like" insect in physical appearance. It is commonly seen in the western hemisphere. As the name suggests, adults of soldier fly are black in colour and can measure up to one inch in length. Likewise, the larvae can be quite large (approximately one inch in length). Adults do not need to feed and are not attracted to homes and live for approximately two weeks. Larvae of black soldier fly are voracious feeders and are capable of consuming most of the organic wastes.

(c) Mosquitoes

In the previous sections, we have already discussed different species of mosquitoes like *Anopheles, Aedes,* etc. Mosquitoes not only causes human diseases like malaria and dengue, but are also responsible for affecting the health of animals, are infamous for their animal-biting habits resulting in nuisance and disease to humans. Worldwide, there are over 3,000 mosquito species found in diverse habitats spanning from the tropics to the near arctic regions. Mosquitoes are known to transmit a number of pathogens that cause serious human and animal diseases such as malaria, dengue, yellow fever, Rift Valley fever, heartworm and encephalitis.

(d) Lice

A variety of lice can infest chickens. These include the chicken body louse (*Menacanthus stramineus*), shaft louse (*Menopon gallinae*), fluff louse (*Goniocodes gallinae*), wing louse (*Liperus caponis*), as well as chicken head louse (*Cuclotogaster heterographus*). Out of all these, the chicken body louse is the best known and probably most common species. These species of lice are permanent ectoparasite of domestic chickens i.e., they can complete their complete life cycle on the host. The total number of chicken body louse can reach challenging levels irrespective of housing or production type (caged, cage-free, free-range, or backyard poultry).

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(e) Litter Beetle

The litter beetle (also known as lesser mealworm beetle) is one of the common pests which is associated with commercial (and sometimes backyard) poultry where they can be present abundant in the poultry litter as well as manure. The population of Beetle can reach high levels in both caged as well as cage-free housing systems. Immature beetles can cause substantial structural damage to poultry housing. Adult as well as immature beetles pose serious threat to bird health in cage-free systems as they can carry several pathogens of poultry.

(f) Sticktight Fleas

They are ectoparasitic in nature. Adults of sticktight fleas embed themselves into the skin of chickens, turkeys, as well as that of other animals. They are generally not problematic in poultry systems where birds are housed in cages suspended above the ground. Sticktight fleas are most common in free-range as well as backyard poultry systems. Immature fleas need organic substrate in the litter or soil to develop. This habitat is not available to fleas in caged-bird system

3. Pests of Sheep

(a) The Sheep Bot Fly (*Oestrus ovis*)

Sheep bot fly is a pest of domesticated sheep. It is distributed worldwide. Sheep bot fly is an obligate parasite and the larval stages inhabit the sinus cavities of the host. The female adult of this fly does not lay eggs, but rather ejects first-stage larvae at the noses of sheep, occasionally targeting humans in close proximity to sheep, even though, the fly cannot complete development in a human. Sheep bot fly can be responsible for causing huge economic losses.

(b) Stable Fly

The description of stable fly has already been given above. It is serious pest of cattle's as well as that of sheep.

(c) Blow Flies

Numerous species of blow flies (Diptera, Calliphoridae) infest soiled wool on sheep and are collectively referred to as "wool maggots". The two most important species of blow flies are the black blow fly, *Phormia regina*, and two species of green bottle flies, *Lucilia sericata* and *Lucilia cuprina*. Sometime, other species including the secondary screwworm, *Cochliomyia macellaria*, may be involved as well. All the wool maggot species usually develop in carrion, however, sometimes, blow flies infest wool contaminated with urine, feces or blood, as well as wounds on living animals. Wool maggots feed on dead, necrotic tissues and usually do not invade healthy tissues as do primary screwworms, *Cochliomyia hominivorax*. However, maggots feeding next to the skin cause the wool to loosen in large patches as well as the skin becomes red and raw. Ultimately, the skin becomes necrotic and the maggots invade the tissue, leading to death of the host. Majority

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of the cases of wool maggots occur in the rump regions of ewes shortly after lambing. Other infestation sites include around the horns and in the genital regions. Infestations are most frequent when the weather is cool and damp. Wool in the infested area appears to be bluish-green in colour and is usually loose and falling out in patches. Infestation by wool maggot produce a strong, offensive odor. Treatment for wool maggots involves shearing wool in the infested and surrounding areas and treatment with a suitable insecticide.

4. Pest of Horses

(a) Canyon Flies

These flies are significant pests of humans as well as of animals present in coastal mountain and foothill habitats of the southwestern United States. The canyon fly group involves seven related fly species within the Fannia benjamini complex: *F. benjamini*, *F. conspicua*, *F. thelaziae*, *F. tescorum*, *F. operta*, *F. neotomaria*, and *F. arizonensis*. The distribution of these fly species is not known, even though a few of them overlap in range among species is documented at a few locations where they have been studied. All flies present in this group are attracted to animals to feed on body secretions like tears, mucus, sweat, saliva, or blood oozing out from the open wounds. Their constant attempts to land upon the face as well as body of the host can cause substantial irritation. These flies are active during the day time, with host-seeking usually greatest soon after the sunrise and in the hours before sunset. In regions, having very high temperatures during the day time, a distinct stillness in fly activity will be observed during midday. Very less in known about the variation in activity among the canyon fly species, however, those species that have been examined in California exhibit a different kind of seasonal activity with adult fly abundance peaking during the late spring as well as the early summer or in early-mid fall.

(b) Eye Gnats *(Liohippelates)*

They are commonly known as eye gnats. Flies belonging to the genus *Liohippelates*, which is formerly known as *Hippelates*, are very small and are generally known as 'eye gnats' in their range in North as well as South America due to their tendency for hovering around eye region and other areas with secretions like the nose or open wounds. A very large group of such flies are commonly seen in the southern United States in areas with loose sandy soils. *Liohippelates sp.* do not bite, however, due to their continuous feeding in large numbers at specific times of the year, they lead to extreme annoyance to people. It has also been observed that large populations of *Liohippelates sp.* can reduce weights or have other physiological effects on animals due to persistent as well as unrelieved feeding. In addition to annoyance, this group of flies has been implicated in the transmission of several pathogens to humans and animals including conjunctivitis (pink eye), acute bovine mastitis and vesicular stomatitis.

(c) Horn Fly

Horn flies have already been explained above affect horses too.

(d) Stable Fly

Stable flies have already been explained above affect horses too.

Check Your Progress

12. Name some common species of flea.
13. Which disease is caused by Culex mosquito?
14. Tsetse fly belongs to which genus?
15. Horn flies act as a vector of which disease?

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3.5 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Some common pests of cotton are: Cotton Semilooper, Tarache Notabilis, Green Semilooper, Anomis Flava, Bud Moth, Phycita Infusella, Spodoptera Litura (Fabricius) and Cotton Grey Weevil.
2. *Pyrilla perpusilla* is commonly known as Sugarcane plant hopper.
3. *Pyrilla perpusilla* passes through five nymphal instar stages to reach the adult stage.
4. *Scirpophaga incertulas* is one of the major pests of paddy.
5. Natural enemies of mango hopper are as follows:
    - Parasitoids: Polynema spp., Gonatocerus sp, Tetrastichus sp
    - Predators: Mallada boninensis, Plexippus paykullii
6. holometabolous type of insects are the insects that exhibit all the four stages namely: egg, larva, pupa and adult.
7. Adopting Insect pest control measures would provide the opportunity to the farmers to control the insect pests before they can cause severe crop damage and huge economic loss.
8. Cultural control of pests includes methods like planting, growing and harvesting crops, which will reduce crop damage.
9. A trap crop refers to the small planting of the vulnerable crop made earlier than the main crop. Trap crop is highly attractive to the insect. 'Trap crop' diverts the insect pest from attacking the main crop.
10. A few examples where handpicking technique can be employed effectively are as follows:
    - Locust nymphs which are assembling can be beaten by sticks and brooms.
    - Handpicking of Papilio larvae from citrus plants, sugarcane borer eggs, sawfly larvae on mustard, cabbage butterfly eggs etc. are very effective in small areas.
11. This method is employed for stored grain pests as temperature extremities are fatal to insects. Low temperatures are generally utilized for controlling insects in flourmills and warehouses. Exposing the insects to sub-zero temperature for 24 hours is lethal.
12. A few well known common species are Human flea *(Pulex irritans),* Rat flea *(Xenopsylla cheopis,* Dog and Cat flea *(Ctenocephalides canis,*

Combed Rat flea *(Nosopsylla or Ceratophyllus* sp.*),* Broken-headed mouse flea *(Leptopsylla segnis)* and Rat flea *(Stivalius ahale).*

13. Culex Mosquito causes Filariasis or elephantiasis.

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14. Tsetse fly belongs to genus ***Glossina*** of family Glossinidae.
15. Horn flies have been implemented as a developmental vector (carrier) for *Stephanofilaria stilesi*, a spirurid nematode that causes stephanofilariasis in cattle.

3.6 SUMMARY

- *Spodoptera litura*, commonly known as oriental leafworm is a polyphagous noctuid moth.
- *Pyrilla perpusilla* is commonly known as Sugarcane plant hopper is majorly found is Asian countries like Afghanistan, Bangladesh, Burma, Cambodia, India, Indonesia, Nepal, Pakistan, South China, Sri Lanka, Thailand, as well as Vietnam.
- *Scirpophaga incertulas* is one of the major pests of paddy. It is a very particular pest of paddy and has worldwide distribution.
- Stripped stem borer is considered under the major pests of paddy.
- Insect pests increase the costs of grain both directly via the expense of control on the farm, as well as indirectly via the costs incurred by grain handling authorities in controlling weevils in bulk storages.
- *Rhyzopertha dominica* is one of the most serious pest of stored grain.
- The rice weevil is one of the most serious stored grain pests worldwide.
- *Aleurocanthus woglumi* , a species of whitefly originated in Asia ,is referred to as citrus black fly because of its slate blue colour.
- Red, black and other types of Ants eat as well as carry food material and create annoyance in the kitchen area and house where they crawl in the eatables and other items of use.
- Ants are holometabolous type of insects, i.e., they exhibit all the four stages namely: egg, larva, pupa and adult.
- A few queen ants may survive up to 15 years, or sometimes even decades, if the conditions are favourable.
- The male ants possess wings and hence their sole purpose, is to reach adulthood, is to fly away as well as to mate with queens.
- Worker ants lack wings and usually survive several months with few exceptions of workers who can survive up to seven years.
- Termites eat away any wood article, paper, plants as well as animal products.

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- Termites comprises of a large number of species, approximately 2,750 species that are conspicuously found in tropical rainforests worldwide.
- The female termite lays eggs after fertilization in a jelly-like liquid that holds the eggs together.
- Termites form large colonies and adults of colony are divided into different caste.
- One of the most common type of furniture beetle is a member of the family of Ptinidae beetles.
- Even though the different species of spider beetles differ in physical appearance from each other, majority of them exhibit some resemblance to spiders upon first glance.
- Clothes moths are small insects of dull colour, having a wing span of one centimetre and frequently fly about in houses.
- There are several insect pests that attack pulses. All these insect pests can be categorized as flies, bugs, mites, worms, etc.
- Bean aphid is a greenish black coloured aphid. The entire life cycle completes within 3-8 days.
- Whiteflies comes under the family Aleyrodidae. They are found in abundance on the abaxial surface of leaves.
- Insect pests possess a huge loss to human, nature as well as economy. It can lead to qualitative and quantitative loss of crops.
- A trap crop refers to the small planting of the vulnerable crop made earlier than the main crop. Trap crop is highly attractive to the insect.
- Field burning (Controlled burning) is a more traditional method of controlling pest.
- Insects requires moist conditions to thrive and cannot survive in low moisture conditions. Hence, drying the food grains in sun or using heat blowers can reduce the insect infestation of stored grains.
- Pheromones are the substances that are released into the environment by an individual of a species that elicits a specific social response in members of the same species.
- Biological control refers to the action of natural enemies like parasites, predators as well as pathogens in maintaining another organism's population density at a lower level in nature than would occur normally in their absence.
- Conservation of natural enemies demands judicious and minimal use of insecticides on crops, so that parasites and predators are not unnecessarily killed.
- Biological control of insect pest is a time-consuming long-term process and often takes years before these natural enemies could be well established in crop fields.

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- Genetic control of insect pest involves the procedure of manipulating genetic material of a pest species so as to confer lethality on the species.
- Integrated Pest Management (IPM) refers to the collective methods used for controlling pest.
- Cultural control of pests includes methods like planting, growing and harvesting crops, which will reduce crop damage.
- Arthropods include many species of medical or veterinary importance. Among them, several are responsible for the transmission of some dangerous diseases for humans, such as malaria, Chagas disease, leishmaniasis, African trypanosomiasis, lymphatic filariasis, onchocerciasis, dengue, yellow fever, and Zika.
- Female Anopheles mosquito causes Malaria.
- Culex Mosquito causes Filariasis or elephantiasis.
- Mosquitoes become infected when they bite a person infected with the virus. Infected mosquitoes can then spread the virus to other people through bites.
- House fly is a larger insect, approximately 6-7 mm long, greyish in colour with blackish markings on the body.
- There are about 33 species of sand flies in India, some of which are known to transmit diseases.
- *Musca autumnalis* are commonly known as face flies.

3.7 KEY TERMS

- **Primary grain insects**: Primary grain insects are those insects which have the ability to attack whole, unbroken grains.
- **Reproductive alate**: In a termite colony, the only adults that are capable of reproducing are king and queen termites they are known as reproductive alate.
- **Aphids**: Aphids are small pear-shaped insects having long sucking mouth parts.
- **Thrips**: Thrips are minute winged insects that feed on the leaves as well as flowers causing tiny spots, lesions, and downward leaf curling.
- **Volunteer crops:** Volunteer crops refers to those crops that are self-sown or spilled seeds.
- **Trap crop**: A trap crop refers to the small planting of the vulnerable crop made earlier than the main crop. Trap crop is highly attractive to the insect.
- **Pheromones:** Pheromones are the substances that are released into the environment by an individual of a species that elicits a specific social response in members of the same species.
- **Pheromones traps:** A pheromone trap is used to capture the insect pest using specific pheromones.

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- **Biological control**: Biological control refers to the action of natural enemies like parasites, predators as well as pathogens in maintaining another organism's population density at a lower level in nature than would occur normally in their absence.
- **Systemic insecticides**: Systemic insecticides act on the stomach of the insect pests and kill them.
- **Fumigants**: Fumigants refers to the chemicals which are used for controlling the stored grain pests by the release of toxic gases in the storage houses.
- **Cytoplasmic Incompatibility (CI)**: Cytoplasmic Incompatibility (CI) refers to the phenomenon that results in gametes i.e. sperm and eggs being unable to form viable offspring.

3.8 SELF-ASSESSMENT QUESTIONS AND EXERCISES

Short-Answer Questions

1. Write the control measures of *Pyrilla perpusilla.*
2. Name some ant species which does not undergo metamorphosis into pupas.
3. What are the control measures for termites?
4. What do you understand by resistant varieties of crops?
5. Write the physical or mechanical methods of pest control?
6. Define pheromones.
7. Write the control measures used for head louse.
8. State some methods to control Sand fly.
9. List the disease transmitted by house fly.
10. Write the name of disease and their causative agent spread by various species' of mosquitos.

Long-Answer Questions

1. Explain the life cycle of any one common insect pest of cotton.
2. Describe the life cycle of Citrus leaf miner.
3. Elaborate on ant's hierarchy and castes.
4. Analyze the advantages and disadvantage of using Pheromones in pest control.
5. Explain biological methods of pest control.
6. Describe Integrated Pest Management strategies (IPM).
7. Explain the life cycle of mosquito in detail.
8. Explain life cycle of any one insect of veterinary importence.

3.9 FURTHER READING

NOTES

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UNIT 4 BENEFICIAL INSECTS

NOTES

Structure

4.0 INTRODUCTION

Beneficial insects (sometimes called beneficial bugs) are species of insects that perform valued services like pollination and pest control. In horticulture and gardening, beneficial insects are often considered those that contribute to pest control and native habitat integration. Encouraging beneficial insects, by providing suitable living conditions, is a pest control strategy, often used in organic farming, organic gardening or integrated pest management. Many insects are considered ecologically beneficial as predators and a few provide direct economic benefit. Silkworms produce silk and honey bees produce honey and both have been domesticated by humans. Insects are consumed as food in 80% of the world's nations, by people in roughly 3000 ethnic groups. Human activities also have effects on insect biodiversity.

Honey is perhaps the most economically valuable product from insects. Beekeeping is a commercial enterprise in most parts of the world and many forest tribes have been dependent on honey as a major source of nutrition. Honeybees can also act as pollinators of crop species. Many predators and parasitoid insects are encouraged and augmented in modern agriculture. Silk is extracted from both reared caterpillars as well as from the wild (producing wild silk). Sericulture deals with the techniques for efficient silkworm rearing and silk production. Although new fabric materials have substituted silk in many applications, it continues to be the material of choice for surgical sutures. Lac was once extracted from scale insects but is now replaced by synthetic substitutes. The dye extracted from cochineal insects was similarly replaced by technological advances. The idea of insects as human food, entomophagy, widely practiced in traditional societies, has been proposed as a solution to meet the growing demand for food, but has not gained widespread acceptance in the West.

In this Unit you will study about mulberry and non-mulberry sericulture, apiculture, lac culture, insects and pollination, insect as human food for future and ecological factors effecting the population and development of insects.

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4.1 OBJECTIVES:

After going through this unit you will be able to:

- Understand mulberry and non-mulberry sericulture
- Analyze apiculture
- Explain lac culture
- Comprehended insects and pollination
- Analyze insect as human food for future
- Define ecological factors effecting the population and development of insects

4.2 MULBERRY AND NON-MULBERRY SERICULTURE

Hoshomin, the Queen of China, introduced sericulture for the first time in China. Sericulture which involves rearing of silkworm and reeling of were kept as a national secret by China and its industrial technique was not known in other countries. According to Chinese legend, the technique of producing silk by using *Bombyx mori* was invented at around 2,700 BC when prince Hoang-ti asked his wife Si-ling-chi to learn about silkworm and look for the feasibility of using its thread for textile industry. She is the one who devised not only the technique of culturing silkworm but also the method of reeling the silk and making garments out of it. She was later crowned as "The Goddess of Silk Worm". However, later on, it was introduced into Europe as well as Japan by smuggling the secrets from China through travelling monks. In India, this technique was introduced approximately 400 years ago. The production of silk plays a significant role in the domestic industry of several nations and silk became a precious commodity, highly sought after in all countries. In 139 BC the world's longest highway that stretched from Eastern China to the Mediterranean Sea was opened, which was called "Silk Route" due to trade in silk. Today, India and China are the top producers of silk in the world.

Classification of Silkworms

Silkworms can be classified in several ways:

1. Classification on the Basis of Geographic Distribution

(a) Japanese Race (Aboriginal in Japan)

Fecundity of Japanese race ranges from 600-700. The larval form is very active and leaf cocoon ratio is less. The size of the larva is small and is approximately 26 days. The shape of the cocoon is strangulated giving the appearance of pea nut

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shape. Japanese races produce white cocoons. There are Uni and Bivoltines races in this group. Larvae of the Japanese race are vulnerable to diseases like grasserie and flacherrie.

(b) Chinese Race (Aboriginal in China)

Fecundity of Chinese race ranges from 600- 650 eggs. The shape of the cocoon varies from round to elliptical to spindle shaped. The Cocoon of Chinese race are white, golden yellow, flesh or red in color. The Silk filament is fine and reelability is good. The silkworm belonging to Chinese races are highly resistant to high temperature as well as humidity. Univoltine, Bivoltine and Multivoltine falls under this group.

(c) European Races (Aboriginal in Europe and Central Asia)

Fecundity rate ranges from 550- 600 and size of the eggs is large. The larval stage is long, the moulting period reduced by 1-2 h. The cocoons are big, long and elliptical in shape. Cocoons are either white/flesh coloured. The length of the filament is long with good reelability. European races are usually weak against high temperature as well as humid conditions. All are Univoltines.

(d) South East Asian Races (Tropical)

Fecundity varies from 400-500. Eggs are small. The larval length is short. However, a few exceptions exist like the tropical races of India which show longer larval duration. The size of the larvae is small. The filament is short. The cocoon is spindle shaped. Cocoon is usually green/pink/yellow/white in color. Denier of the silk filament is fine. South East Asian races are resistant to different environmental conditions particularly high temperature as well as humid conditions. Multivoltines/ polyvoltine races are very common.

2. Classification of Silkworms Based On Voltinism

Voltinism indicates the number of broods or generations of an organism in a year under natural environmental conditions. On the basis of voltinism, *Bombyx mori* is divided in to 3 types, namely:

(a) Univoltine Races: Univoltine races produce one generation per year.

(b) Bivoltine Races: They produce two generations per year.

(c) Multivoltine Races: They produce more than 5-6 generations per year.

3. Classification Based On Moultinism

Moulting - Moulting or molting, also known as shedding, or ecdysis, refers to the phenomenon of casting outer layer of skin at specific points in the life cycle of organism. Silkworms can be classified in to tri moulters, tetra moulters, penta moulters and hexa moulters.

(a) Trimoulters: This group includes silkworms which moult three times during larval period.

(b) Tetramoulters: This group moults four times during their larval stage.

(c) Pentamoulters: This moults five times during their larval stage.

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Silkworm Species in India

Sericulture refers to the process of cultivating or growing silkworms. The production of silk plays a significant role in the domestic industry of several nations. The top producers of silk in the world are India and China. Sericulture generally involves three steps- Moriculture, Silkworm rearing, and reeling of silk. Moriculture refers to the process of cultivating mulberry leaves; Silkworm rearing refers to a process where the growth and development of silkworms are promoted; Reeling of silk refers to the process of extracting silk fibre from the cocoons of silkworms. Five major species of silk worms reared in India are as follows:

1. *Bombyx mori*- the Mulberry silk worm

Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Order:	Lepidoptera
Family:	Bombycidae
Genus:	*Bombyx*
Species:	*B. mori*

This silkworm species feeds on the leaves of mulberry (*Morus alba)* to produce the best quality silk fibre. Morus alba, is also known as white mulberry, common mulberry or silkworm mulberry, is a fast-growing, small to medium-sized mulberry tree which grows up to 10–20 m tall. It is generally a short-lived tree having a lifespan comparable to that of humans, even though, there are few specimens known to be more than 250 years old. The species is native to central China and is widely cultivated and naturalized elsewhere. Figure 4.1 is depicting the male and female of *Bombyx mori*.

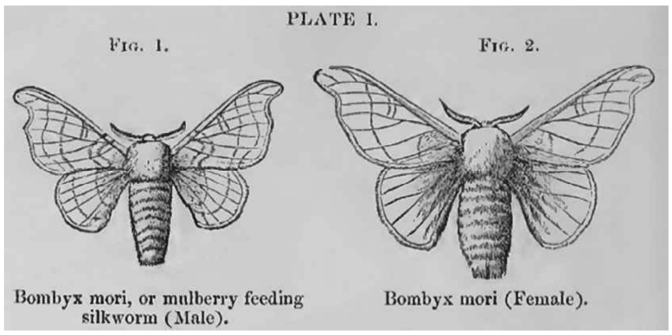

Fig.4.1 *Male and Female of Bombyx Mori*

2. *Antherea paphia or Antherea mylitta-* the **Tasar silk worm**

Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Order:	Lepidoptera
Family:	Saturniidae
Tribe:	Saturniini
Genus:	*Antheraea*
Species:	*paphia, mylitta*

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Tasar silkworm feeds on *Terminalia tomentosa* that occurs in the forests of Bihar, Madhya Pradesh, UP and Orissa. Other Common Names of this tree are: Taukkyan (Burma), Sadar, Matti, Asan, Marda(India). It is widely distributed in India and Burma region. The Tree may reach a height of 100 ft and more; with clear, straight boles to 70ft; trunk diameters about 3 ft.

Fig. 4.2 *Antherea paphia*

3. ***Antherea royeli*** and ***Antherea perniyi,***- the **Oak tasar silkworms**

Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Order:	Lepidoptera
Family:	Saturniidae
Tribe:	Saturniini
Genus:	*Antheraea*
Species:	*Perniyi/royeli*

Oak tasar silkworms feed on oak trees and were introduced from foreign countries. An oak is a tree or shrub in the genus Quercus of the beech family, Fagaceae. There are around 500 extant species of oaks. The common name "oak" also appears in the names of species in related genera, particularly Lithocarpus, and in those of unrelated species like Grevillea robusta and the Casuarinaceae. The genus Quercus is native to the Northern Hemisphere, and includes deciduous and evergreen species extending from cool temperate to tropical latitudes in the Americas, Asia, Europe, and North Africa.

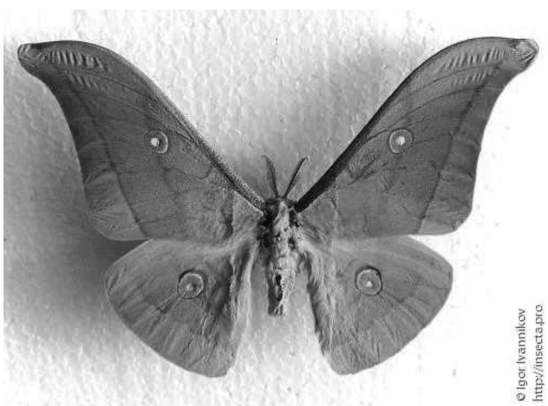

Fig.4.3 *Antherea royeli*

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4. *Antherea assamensis-* the **Muga silk worm**

Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Order:	Lepidoptera
Family:	Saturniidae
Tribe:	Saturniini
Genus:	*Antheraea*

The muga silkworm is confined to the Brahmaputra Valley of India and produces the famous muga silk. The larva feed on *Cinnamomum*, *Laurus*, *Litsea*, *Carpinus*, *Persea*, *Magnolia*, *Michelia*, *Quercus*, *Sarcostemma* and *Symplocos*.

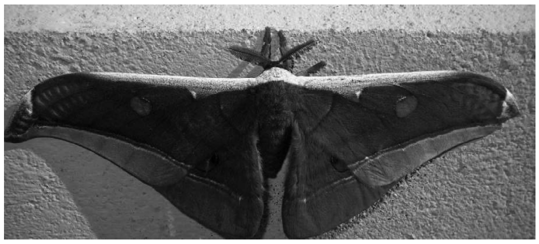

Fig.4.4 *Antherea assamensis*

5. *Phylosamia ricini,* the **Eri silkworm**

Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Order:	Lepidoptera
Family:	Saturniidae
Genus:	*Phylosamia*
Species:	*ricini*

Eri silkworm feeds on castor ***(Ricinus communis)*** is raised in Assam, Madhya Pradesh, Rajasthan and Orissa commercially. Ricinus communis, the castor bean or castor oil plant, is a species of perennial flowering plant in the spurge family, Euphorbiaceae. It is the sole species in the monotypic genus, Ricinus, and subtribe, Ricininae.

Fig. 4.5 Phylosamia ricini

NOTES

1. Mulberry Silkworm

Mulberry plantation

Morus alba, M.indica, M. serrata and ***M.laevigata*** are the four Indian species of mulberry. These species are cultivated on main food plants of silkworm. In India, the climatic conditions vary from state to state. Hence, in Indian states, where the temperature ranges from 16°C to 31°C, mulberry silkworm can be reared throughout the year. For instance: Karnataka, where the temperature ranges from 16-31 degree centigrade, provides ideal climatic conditions for rearing mulberry silkworm throughout the year. On the contrary, in West Bengal, the multivoltine silk-worm rearing is practised even under adverse temperature conditions. In Jammu and Kashmir univoltine variety of silkworm is cultured only once a year during May-June.

Life Cycle of Mulberry Silkworm

The overall life cycle of the silkworm is approximately 6-8 weeks. Silkworm is a holometabolous insect and pass through four different stages of life cycle i.e., egg, larvae, pupa and adult. The various stages of life cycle of silkworm are as follows:

(a) Egg: The female silkworm produces or lays eggs. Laying of eggs marks the beginning of the life cycle of the silkworm. The egg of the silkworm is dot-sized. At a time, the female silkworm can lay approximately 350 eggs. The eggs hatch under warm temperatures.

(b) Silkworm larva stage: Egg hatches under warm conditions. The larval form of silkworm is hairy and last approximately for 24 to 33 days. Larvae is a voracious feeder. Silkworm larvae depend on mulberry leaves for food. The maximum growth of the organism takes place during this stage.

(c) Cocoon stage: This stage of the silk moth begins after 30 days. During cocoon stage, the silkworm tends to turn translucent and yellowish in colour. At cocoon stage, silkworm develops a protective covering around itself. This protective covering or layer is known as the cocoon. The cocoon comprises of a single silk thread whose size is almost that of a tiny cotton ball. The approximate time taken to develop the entire cocoon is just 2 days.

(d) Pupa: At pupal stage, silkworm exhibits no movement or motion at all. It is the pupa stage where people loosen up the silk thread by killing the pupa by diving the cocoon into the bubbling water.

(e) Silkmoth: The development of the silkmoth from the cocoon stage takes approximately 10 to 14 days. The transformation of the pupa into a silkmoth completes its life cycle.

Once the silk moth attains maturity, it begins to look for a mating partner. The silk moth releases chemical substances known as pheromones to attract partners for mating. Once mating completes, the female silk moth produces 350 eggs on the surface of mulberry leaves. These eggs begin their life cycle individually. Figure 4.6 is depicting the life cycle of *Bombyx species.*

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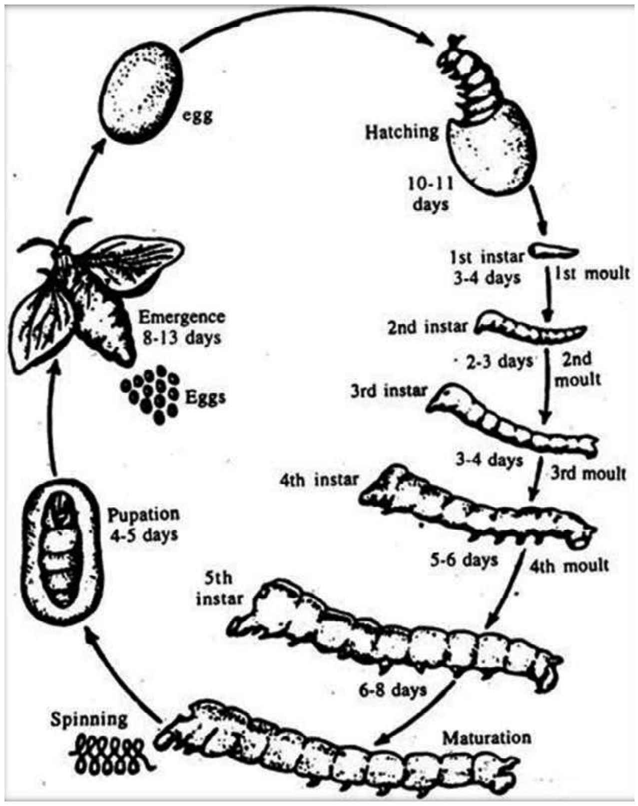

Fig. 4.6 *Life Cycle of Bombyx Species*

2. Non-Mulberry Silk Worms

(a) Tasar Silk Worm

Three species of ***Antherea*** namely ***Antherea mylitta, A. perniyi*** and ***A. royeli*** are used for the extraction of tasar silk in India. ***Antherea mylitta*** contributes to approximately 400 tonnes of non-mulberry silk produced in India. *Antherea mylitta* feeds on ***Terminalia tomentosa*** and ***Terminalia arjuna*** found in the forests of central as well as north-eastern parts of India. The tasar silkworms is a wild species and therefore the cocoons are also gathered by the tribal people from forests to get silk. The first crop, usually known as the seed crop is raised from the months of May to July, however, the commercial crop is raised during the month of October-November.

Fig. 4.7 *Terminalia arjuna*

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The larvae of tasar silkworm are generally green in colour and moults four times before they complete their larval duration. Even though, the larvae are generally green in colour, yet, yellow, blue and white larvae are also frequently reported. At the end of the larval period, they spin a ring like structure around the twig and a long stalk from which the cocoon hangs. The cocoons are large and brown or yellow in colour. Moths emerge out from the cocoons in the month of June. In order to get silk, cocoons are cooked in caustic potash and reeled to extract out the fibre and then spun to manufacture coarse thread. Figure 4.8 is depicting the life cycle of *Antherea mylitta.*

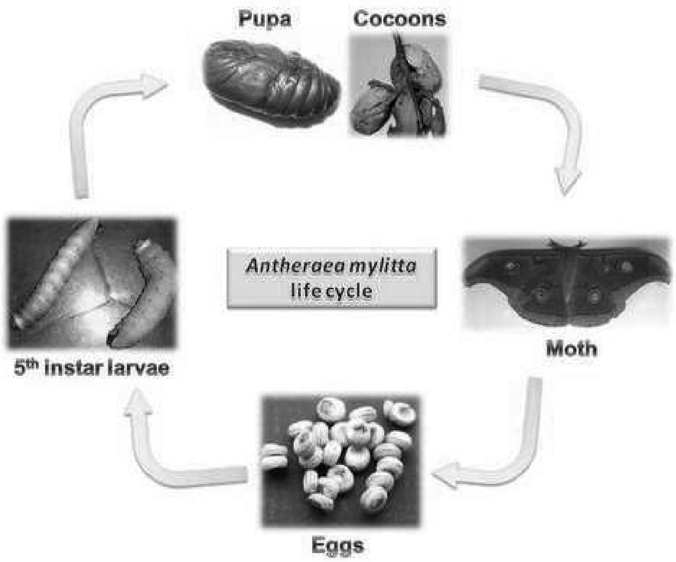

Fig. 4.8 *Life Cycle of Antherea Mylitta*

(c) Muga Silk Worm

Muga silk is found only in in the Brahmaputra Valley of India. Muga silk is a golden-yellow silk produced by ***Antherea assama***. Muga silkworm is a semi-domesticated species as the larval form which generally crawl down of trees at the end of their larval period are collected and allowed to spin cocoons in captivity. ***Antherea assama*** produces high quality golden yellow silk. The larval forms are fed on Som (***Marchilus bombycina)*** and Soalu ***(Litsaea polyantha)*** trees. Silkworms are ready to spin cocoons towards the end of the larval period. As soon as the larvae are ready, they climb down the trees to look for suitable grounds for spinning cocoons. To get silk, the cocoons are boiled in a mixture of soap and soda solution and are then reeled on a machine**.** India produces approximately 50 tonnes of muga silk. A single Muga female moth can lay approximately 150-200 eggs after copulating with the male for around 6-8 hrs. The larvae are yellowish in colour with black markings on the body and have the routine of crawling down the trees in groups as soon as all the leaves are consumed on the trees and larvae have matured. If the larvae have not matured and the leaves on the trees fully eaten up, they can be shifted to another suitable tree. The larvae crawls down after the end of larval period to spin cocoons. Figure 4.9 is depicting the life cycle of Muga silkworm.

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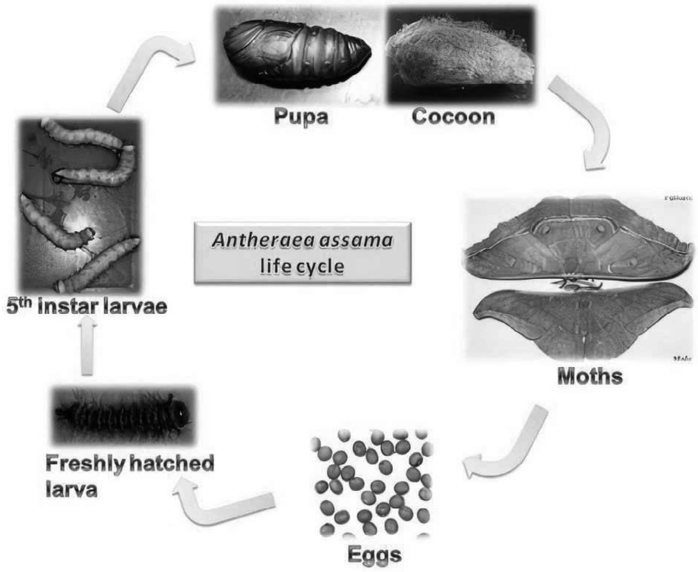

Fig, 4.9 *Life Cycle of Muga Silkworm*

(d) Eri Silk Worm

Philosamia ricini is grown in Assam as well as in the eastern parts of India. The atmospheric conditions like heavy rainfall as well as humid atmosphere in these parts of India are beneficial to eri culture. Castor plant is the preferred food choice for eri silkworm. This silk worm is multivoltine i.e., produces 5-6 generations per year and is reared indoors. The eggs of eri silkworm are white in colour and hatch within ten days. The hatched larvae are mounted on castor leaves in the rearing-houses and are then allowed to grow by feeding on leaves. During its life cycle, the eri silkworms moult four times and the larval period is of 30-32 days. Eri silkworm is usually hardy and not vulnerable to diseases. At the end of larval period, when the larva is ready, it crawls to look for a suitable ground to spin cocoons. The cocoons of the eri silkworm cannot be reeled, as they are made up of numerous small fibres and therefore the emergence of moths is allowed and the cocoons are spun like cotton to produce yarn. The annual production of eri silk in India is around 90 tonnes. Figure 4.10 is depicting the life cycle of Eri silkworm.

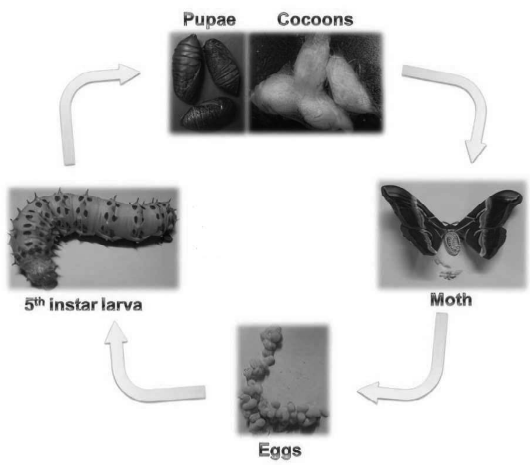

Fig. 4.10 *Life Cycle of Eri Silkworm*

Production of Silk:

The production of silk can be divided into nine stages as follows: -

1. **Stage 1- Drying/ Stifling:** Drying or stifling refers to the killing of pupa present inside the cocoon so as to make them suitable for storage. The cocoons are stifled either by direct method like sun drying or heating or indirect methods like steam or hot air drying. After the drying/stifling process, the cocoons can be stored/preserved without any further damage to the shell.
2. **Stage -2- Storage:** The cocoons having the dead pupae inside, can either be used for reeling purpose or can be stored up to six months before beginning with the process of reeling. During storage, cocoons should be protected from pest/pathogen/bacterial/fungal attack.
3. **Stage-3- Sorting:** Cocoons are sorted on the basis of some physical characteristics**:**
   (a) Colour
   (b) Shape
   (c) Weight
   (d) Shell weight
   (e) Filament diameter

   During sorting, good /high quality cocoons are separated from bad quality cocoons like the stained cocoons, irregular cocoons, flossy cocoons or thin end cocoons.
4. **Stage-4- Cooking:** Once the good quality cocoons are sorted from the bad ones, they are further softened or cooked by hot soft water in order to swell and soften the sericin present in the cocoon without completely dissolving it. Cooking can be done by different methods —
   (a) Open pan cooking (single basin)
   (b) Three pan cooking

In both open pan as well as three pan cooking, boiling should not be done for long time and the pH of water should range 6.8-7.4. Figure 4.11 is depicting the three-pan basin for cooking process.

Fig. 4.11 *Three Pan Cooking Method*

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5. Stage- 5 - Deflossing/Brushing

Floss refers to the unreelable, tangled mass of silk, found on the outside of cocoons. Deflossing refers to the process of removal of the floss. This is done in order to look for the actual reeling ends of the cocoon that can undergo continuous reeling. In India, deflossing is primarily done by peeling off the floss layer with hand. However, it can also be done with simple device like brush or broom made up of bamboo root sticks to save both time as well as labour. Figure 4.12 is depicting the deflossing of cocoon by brush.

Fig.4.12 *Deflossing of Cocoon by Brush*

6. Stage-6- Reeling

Reeling begins after the process of cooking and brushing. Reeling refers to the extraction of continuous silk thread of a desired thickness from the cocoon without any nick/break. Before reeling, light brushing of the cocoon surface is done in order to look for the tip of the silk filament. After this, all the ends are separated out and gathered together, this is referred to as end picking. Usually, silk filaments from multiple cocoons are gathered together and transferred onto the reeling or spinning machine, which then automatically unravels the cocoons and simultaneously leads to the formation of a single strand of silk from the cocoons. Throughout the process of reeling, the cocoons remain in boiling water. Whenever one cocoon gets exhausted, the second one is immediately substituted to reel a continuous as well as uniform yarn. Hence, it can be concluded that the crucial process in reeling is brushing, end picking, casting, binding and traversing. Figure 4.13 is depicting the process of end picking from multiple cocoons before reeling.

Fig. 4.13 *Process of End Picking*

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The individual filament obtained should be inter-wined or twisted and cemented firmly in such a way that the reeled filament does not break during subsequent processing of fabrics. Croissure, a special kind of device is used to twist as well as to cement the filament. Croissure remains attached with the reeling machine. Apart, from this croissure also helps in taking out the excessive water from the reeled thread. Reeling can be done in three ways:

(a) Charkha-Reeling: Charka reeling is a manually operated system where inferior quality or defective cocoons are reeled. In charkha reeling, both cooking as well as reeling are accomplished in one basin. Following cooking at high temperature, the soften cocoons float in basin. The reeling ends are usually taken from 4-5 cocoons and twisted around themselves with the help of charkha reel to make uniform thread. Charkha reeling is still used primarily in villages for small scale production of silk. The croissure used in charkha reeling is of chambon type where threads from two reeling ends are intertwined to form few spirals.Figure 4.14 depicting the Charkha reeling.

Fig. 4.14 *Charkha Reeling*

(b) Cottage Basin System: Cooking and reeling are done separately in cottage basin reeling system. Boiling water basin is used for the purpose of cooking whereas for reeling a hot water basin which is kept near the cooking basin is used. Croissure used in a cottage basin reeling machine is travellette croissure. It comprises of three pulleys to enable the thread to inter- wine around itself and also for the better removal of water as well as gum spots from the thread. After being squeezed by the croissure, the thread is further dried as it passes on the traverse before reaching the reel. Hence, it can be concluded that the cottage basin system gives better quality of silk having uniform thickness throughout when compared to charkha reeling system.

(c) Filature System: Cooking as well as reeling are done separately in this power-driven system. Filature system is a modern device where continuous reeling is done from cocoons of superior quality. Filature system produces high quality of silk. The silk produced is clean as well as having uniform thickness throughout.

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Stage- 7- Chemical Processing of Raw Silk:

As we can see from above, the raw silk produced is rigid, stiff and not soft in touch and also lacks in lustre due to presence of sericin and other impurities on the surface. Hence, raw silk undergoes following treatments:

(I) Degumming of silk: Degumming of silk refers to the process of removal or elimination of sericin as well as other impurities from raw silk. It is done to make the raw silk clean, soft and shiny. It is carried out by following treatments:

- **(a) Extraction with water:** In this process, silk thread is treated with hot water having a temperature range of 100-130°C for 30 minutes to 4 hours. This leads to degumming of sericin. Extraction with water is a much safe and sound process as it causes minimum degradation to the silk fibre.
- **(b) Treatment with alkali/acid:** Degumming with either alkali or acid depends on a lot of factors like pH, temperature, time of treatment, strength as well as nature of the chemical reagents used. Chemicals like sodium carbonate and bicarbonate, caustic soda, trisodium phosphate etc are generally used for degumming with alkalis. It should be done for 30 minutes to 2 hours at a pH > 8.5 to remove sericin. Similarly; treatment with acidic reagent is done at a pH < 3.0 to eliminate sericin.
- **(c) Digestion with enzymes:** Enzymatic digestion by proteolytic enzymes like trypsin (pH 8.0), papain (pH 5.2), chymotrypsin, and pepsin at a temperature of 40-50°C were proved to be useful for degumming.

(II) Weighting of silk: Weight loss occurs due to the removal of sericin from the silk. Removal of sericin leads to a weight loss of approximately 22-25%. Hence, the silk becomes further expensive. Thus, in order to compensate such weight loss silk is treated with suitable compounds that helps in adding extra weight or fix colour to the silk. Heavy metals like iron, tin, lead zinc, etc. and organic compounds like some tanning substances are generally used for weighting of silk. Weighting can be done by following steps:

- (a) Firstly, the degummed silk is immersed in an acidic solution of tin-tetrachloride.
- (b) As soon as the threads absorb the salt to the point of saturation, excess solution is then discarded by the process of centrifugation. After this, the material is washed thoroughly with cold water to remove the acid. This is followed by treating the thread with hot solution of disodium phosphate.
- (c) This step involves the addition of PO_4 (phosphates) to the tin radical bound in the silk. This treatment is referred to as pass. However, it should be time bound. If this process is allowed for longer duration, the silk will absorb more tin-tetrachloride. Subsequently, the material is again treated with hot solution of Na silicate to increase the weight of silk and to fix the tin-salts uniformly.

However, it should be done carefully as the temperature and concentration of silicate bath control the ultimate weighting of the silk in exact amount.

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Stage-8- Re-Reeling

Even after reeling, it has been observed that silk might have few defects like short length, broken threads, entanglements, hard gum spots, etc. All these defects can lead to a lot of wastage. To overcome these defects, silk is first reeled on small reels and later is transferred to standard sized hanks. This process is known as re-reeling.

Stage-9 - Lacing and Skeining

The Re-reeled silk hunk is then tied with a coloured silk thread by the two ends. The hunk obtained is divided into five parts and is laced with a cotton thread. This lacing prevents entangling of the silk in later stages. The hunk obtained is placed on a skeining machine to be skeined. During this process, the hunk is twisted as well as folded upon itself to form a number of tight spirals or skeins. The skeining prevents ruffling as well as further entanglement of filaments during the process of packing. The skeins obtained are then made into books. In a book, eight skeins are arranged horizontally whereas five skeins are arranged vertically. Each book is then tied with the help of separate cotton bands at three different places and wrapped with tissue paper. Books are kept in bales of twenty kg weight. Thus, silk threads are kept in store house as bales. Store house should be free from humidity as well as air. Figure 4.15 depicting the spiral skeins of silk thread.

Fig. 4.15 *The Spiral Skeins of Silk Thread*

Properties of Silk

(a) Lustre: Silk is a highly lustrous fibre among all the natural fibres. However, wild silk is not as lustrous as cultivated silk.

(b) Structure: Silk is a transparent, lustrous filament with somewhat irregular diameter. The cross section of the silk filament depicts wedge shape. The silk that comes from each cocoon is composed of two filaments held with their wedge shape together with the help of sericin. Silk is the only natural filament fibre. Silk fibre is estimated to be 70-75% crystalline and correspondingly 30-25 % amorphous.

(c) Strength: Silk – the most stunning of all textile fibers is well-known as the

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queen of fabrics. It comes from the cocoon of the silkworm as well as needs a large amount of handling and caring. This makes it one of the costliest fibers too. It is one of the strongest fibre of all natural fibres. However, as compared to synthetic fibres, its tenacity may fall in mid-range. The degree of fibre orientation as well as hydrogen bonding accounts for the good strength of silk fibre. Highly durable fabrics can be made from silk at lower weight also. The durability of silk fabric depends on the factors like use of ply/double yarns as well as compactness of construction.

(d) Elasticity: The elasticity of silk fabric varies on the basis of the yarn used as well as the construction of the fabric.

(e) Resiliency: The resiliency of silk may be graded as medium range. However, silk fabrics retain the shape as well as resist winkling. Delayed recovery is often observed. Heavily weighted fabrics wrinkle more and show decreased resilience.

(f) Abrasion resistance: Silk shows medium resistance to abrasions. The smooth surface and wedge shape of the silk fabric helps in resisting the abrasion.

(g) Drapability: Silk is one of the wonder fabrics that shows good drapability.

(h) Density: Silk fibre shows a specific gravity or density of 1.64 gm/cubic centimeter. It is possible to make light weight silk fabrics without sacrificing the strength.

(i) Absorbency: Silk fabric can absorb water up to 1/3rd its weight without feeling wet to the touch. This property enables silk to take up dyes very well during dyeing and printing. Bottom of Form

(j) Dimensional stability: Silk fabrics retain their shape as the shrinkage in washing is found to be minimum. Crepe fabrics shrink more during laundering however it can be restored back with careful steaming.

(k) Thermal property: Silk is a protein fibre and exhibits lower thermal conductivity when compared to cellulosic fibres. Silk fibres burns slowly in flame giving a hair burnt smell and hence it does not support combustion.

(l) Effect of alkalies: Silk is highly susceptible to alkalies. However, the action of alkalies is slower when compared to wool. Silk gets dissolve easily in caustic soda. Neutral soap is highly suggested for washing.

(m) Effect of acids: Silk is highly resistant to organic acids. However, silk fibroin also gets damaged on applying mineral acids. Silk exhibits the specific property of absorbing as well as holding acid molecules which tend to damage silk fibroin on storage.

(n) Effect of bleaches: Silk is highly resistant to mild bleaches like hydrogen peroxide or sodium perborate. It gets damaged on applying chlorite bleaches.

(o) Effect of Sunlight: Silk is damaged on exposing to sunlight. It is suggested to dry silk in shade.

(p) Effect of Mildew: Silk is not susceptible to mildew unless left in damp condition for a long time.

(q) Effect of Moths: Silk has high resistance to moths as well as silver fish. However, beetles are capable of destroying the silk fibre.

(r) Effect of Perspiration: Silk is damaged when perspiration is left in garments after washing.

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Care of Silks: Silk fabrics are usually considered as clean fabrics. Due to the filamentous nature of silk, it does not hold much soil. Cleaning of the silk is simple and does not need any friction. Mild soaps can be used for washing of silks. However, it is generally recommended to dry clean the silk.

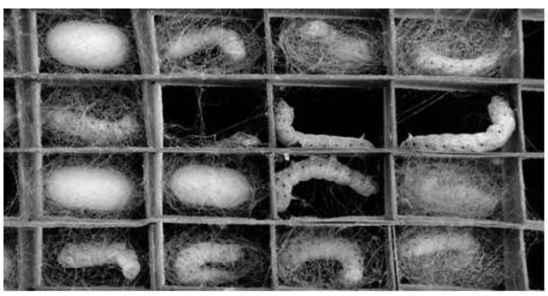
Type of Silk

Four types of natural silk are commercially known and produced worldwide. Among them, mulberry silk is the most significant silk and contributes approximately 90% of world production, hence, the term "silk" in general refers to the silk of the mulberry silkworm. Three other commercially important types fall into the category of non-mulberry silks namely: Eri silk; Tasar silk and Muga silk. Apart from this, there are other types of silk too which are known as non-mulberry silk. Non-mulberry silk is majorly wild and exploited in Africa and Asia. For instance:- Anaphe silk, Fagara silk, Coan silk, Mussel silk and Spider silk are non-mulberry silk.

Mulberry Silk

Majority of the commercial silk produced worldwide is referred to as mulberry silk. Mulberry silk comes from the silkworm, *Bombyx mori* which solely feeds on the leaves of mulberry plant. These silkworms are completely domesticated and reared indoors. Mulberry silk contributes approximately 90% of the world silk production. Figure 4.16 is depicting the mulberry silkworm feeding on mulberry and the pupae of mulberry silkworm**.**

(a)



(b)

Fig. 4.16 *(a) Mulberry Silkworm Feeding On Mulberry (b) Pupae of Mulberry Silkworm.*

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Tasar Silk

The tasar silkworms are wild silkworms and belong to the genus *Antheraea*. There are numerous varieties like Chinese tasar silkworm, *Antherae pernyi Guerin* which produces the largest quantity of non-mulberry silk worldwide; the Indian tasar silkworm, *Antheraea mylitte Dury* and the Japanese tasar silkworm *Antheraea yamamai Querin* which is seen in Japan and produces green silk thread. The Chinese as well as Japanese tasar silkworms feed on oak leaves and other allied species. The Indian tasar worms feeds on leaves of Terminalia and numerous other minor host plants. The worms are either uni- or bivoltine and their cocoons like the mulberry silkworm cocoons can be reeled into raw silk.

Eri Silk

Eri silkworm belongs to two species namely *Samia ricini* and *Philosamia ricini*. *P.ricini* (also known as castor silkworm) is a domesticated one and can be reared on castor oil plant leaves to produce a white or brick-red silk commonly known as Eri silk. As the filament of the cocoons spun by these worms is neither continuous nor uniform in thickness, the cocoons cannot be reeled and, hence, the moths are allowed to emerge and the pierced cocoons are then used for spinning to produce the Eri silk yarn. Figure 4.17 is depicting the Eri silkworm.

Fig. 4.17 *Eri Silkworm*

Muga Silk

Antheraea assamensis belongs to the muga silkworm. It also belong to the same genus as tasar worms, however, it produces an unusual golden-yellow silk thread which is very attractive as well as strong. Muga silk are found exclusively in the state of Assam, India and feed on *Persea bombycina* and *Litsaea monopetala* leaves and those of other species also. The quantity of muga silk produced is quite small and is mostly used for the making of traditional dresses in the State of Assam (India) itself.

Anaphe Silk

This silk of southern as well as central Africa is produced by silkworms of the genus *Anaphe*. The most common species belonging to the genus *Anaphe* are *A.*

moloneyi Druce, *A. panda Boisduval*, *A. reticulate Walker*, *A. ambrizia Butler*, *A. carteri Walsingham*, *A. venata Butler* and *A. infracta Walsingham*. They spin cocoons in communes, all enclosed by a thin layer of silk.

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Anaphe silk is collected by tribal people from the forest and spin the fluff into a raw silk. The silk obtained is soft as well as lustrous. The silk which is obtained from *A. infracta* is locally called as "book", and those from *A. moleneyi* as "Trisnian tsamia" and "koko" (Tt). The fabric is elastic as well as strong when compared to mulberry silk. Anaphe silk is used, for instance, in velvet as well as plush.

Fagara Silk

Fagara silk is obtained from the giant silk moth known as *Attacus atlas* as well as a few other related species or races inhabiting the Indo-Australian bio-geographic region, China and Sudan. Giant silk moth spin light-brown cocoons nearly 6 cm long with peduncles of varying lengths (2-10 cm).

Coan Silk

The larvae of *Pachypasa atus*, from the Mediterranean bio-geographic region (southern Italy, Greece, Romania, Turkey, etc.), feed majorly on trees like pine, ash cypress, juniper and oak. They spin white cocoons measuring approximately 8.9 cm x 7.6 cm. In ancient times, coan silk was used to make the crimson-dyed apparel worn by the dignitaries of Rome; even though, commercial production came to an end long ago due to limited output as well as the emergence of superior varieties of silk.

Mussel Silk

Unlike the non-mulberry silk mentioned above, mussel silk is obtained from a bivalve, known as Pinna squamosa which is found in the shallow waters along the Italina as well as Dalmatian shores of the Adriatic. The strong brown filament, or byssus, is secreted by the mussel to anchor it to a rock or other surface. The byssus is combed and then spun into a silk commonly referred to as "fish wool". The production of mussel silk is mostly confined to Taranto, Italy.

Spider Silk

This is another non-insect variety kind of non-mulberry silk. Spider silk is soft as well as fine, however, it is also strong and elastic. The commercial production of this silk comes from certain Madagascan species, like *Nephila madagascarensis*, *Miranda aurentia* and *Epeira*. The spinning tubes (spinne-rules) are located in the fourth and fifth abdominal segments, and approximately around a dozen individuals are restricted by their abdominal part to a frame from which the gathered fibre is reeled out four or five times in a month. Due to its high cost of production, spider silk is not used at all in the textile industry; even though, durability as well as resistance to extreme temperature and humidity make it essential for cross hairs in optical instruments.

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Check Your Progress

1. Who introduced sericulture for the first time?
2. Name the group of silkworms which moult three times during larval period.
3. Define sericultue.
4. Name the four Indian species of mulberry.

4.3 APICULTURE

Honeybees are native to the Eurasian as well as African continents and were introduced to the Americas and Australia by European settlers. In India, the genus ***Apis*** has the following species:

(a) ***Apis mellifera***- the western honey bee

(b) ***Apis cerana indica***- the eastern honey bee

(c) ***Apis dorsata*****-** the rock bee

d) ***Apis florea***- the small bush bee

In this section, we shall discuss these species briefly.

(a) *Apis mellifera*- The Western Honey Bee or the European Bee

Apis mellifera is not native to India, however, it has been introduced from USA as well as other European countries for increasing the production of honey in apiaries. *Apis mellifera* is somewhat bigger in size as well as lighter in color. It has higher capacity to produce honey when compared to other honeybee species and hence is favored by apiarists. However, this particular species is also prone to diseases like American foulbrood which sometimes destroys large number of colonies. Figure 4.18 is depicting the *Apis mellifera.*

Fig. 4.18 *Apis Mellifera*

(b) *Apis cerana indica*- The Asiatic Honey Bee

Apis cerana is a medium sized honey bee having transverse stripes on the abdominal region. It is found in southern Asia as well as other countries in the Himalayan Range, namely, Afghanistan to Indonesia and also in Japan, Malaysia and Thailand where temperate fruits bloom and provide abundant source of

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nectar. In India, the subspecies of *Apis cerana* i.e., *Apis cerana indica* is still found in the wild specially in the Himalayan belt and can survive very low temperatures. This species nests in tree holes as well as crevices of rocks. *Apis cerana indica* can be domesticated easily by farmers for honey production as this species has gentle temperament and makes hive in enclosed spaces. Figure 4.19 is depicting the *Apis cerana indica.*

Fig. 4.19 *Apis Cerana Indica*

(c) *Apis dorsata*- The Rock Bee

Apis dorsata is a large wild honey bee commonly found in the forested area of southern Asia. As the name suggests, this species built their hives in exposed places located far above the ground like the branches of trees or under the cliffs of rocks as well as ceilings of ruins and abandoned buildings. The hive is composed of a single vertical comb, sometimes more than a metre in length. In March-April, i.e., during the breeding season, these bees swarm and migrate to different places in the forests looking for nesting sites. Figure 4.20 is depicting the *Apis dorsata.*

Fig 4.20 *Apis Dorsata*

(d) *Apis florea*- The Dwarf Honeybee or Bush Bee

Apis Florea is the smallest honey bee. It is considered to be the most primitive honey bee species. This species is brownish in color but the basal part of abdomen is always red. There is another species known as ***A. andreniformis*** which is darker in colour and the first abdominal segment is totally black. Figure 4.21 is depicting the *Apis florea.*

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Fig. 4.21 *Apis Florea*

Life Cycle of Honey Bee

The classification of different species of honey bee are as follows:

1. ***Apis mellifera***

   DOMAIN - Eukarya

   KINGDOM - Animalia

   PHYLUM - Arthopoda

   CLASS - Insecta

   ORDER - Hymenoptera

   SUPERFAMILY - Apoidea

   FAMILY - Apidae

   GENUS - *Apis*

   SPECIES - *mellifera*

2. ***Apis cerana***

   DOMAIN - Eukarya

   KINGDOM - Animalia

   PHYLUM - Arthopoda

   CLASS - Insecta

   ORDER - Hymenoptera

   SUPERFAMILY - Apodea

   FAMILY - Apidae

   GENUS - *Apis*

   SPECIES - *cerana*

3. ***Apis indica***

   DOMAIN - Eukarya

   KINGDOM - Animalia

   PHYLUM - Arthopoda

   CLASS - Insecta

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ORDER - Hymenoptera

SUPERFAMILY - Apodea

FAMILY - Apidae

GENUS - *Apis*

SPECIES - *indica*

The scientific name of honey bee is 'Apis', which is derived from Latin word for 'Bees'. Most of the European honey bees fall under *Apis mellifera*; with 'mellifera' being the Latin word for "honey-bearing". The entire process of culturing and rearing honey bees for acquiring honey as well as other bee products is known as apiculture or beekeeping. Apiculture is an old tradition that started with hunters in the forest in search of sweet honey.

Life Cycle of Honeybee

Honey bees are the primary reason for the process of pollination. Honey bees have the ability to travel around 20 miles per hour when gone for pollination and around 17 miles per hour while carrying the nectar back to the beehive. Due to this very reason, the entire process of pollination runs faster and more efficiently. Honey bees are holometabolous with life cycle depicting all four stages i.e., egg, larvae, pupa and adult. The description of different stages of life cycle of honey bees are described below: -

Stage 1 – The Egg Stage

The virgin queen takes to nuptial flights for mating and then settles in the hive for laying eggs. Queen bee is the only female bee in the entire honey bee colony which is capable of laying approximately 2,000 to 3,000 eggs per day. However, the normal fecundity is approximately 600 eggs/day. The egg is positioned upright and falls on the side by the third day. The queen bee lays both fertilized egg as well as unfertilized egg. Queen bee can produce fertilized or unfertilized eggs on her own choice. The fertilized egg develops into female bees (worker bees) or queen bees. The unfertilized egg hatches to form male bees also known as drone bees. Males are darker, robust and hairy and larger than workers. There are about two dozen of them in a hive and chase the queen in air every time she ventures on nuptial flight

Stage 2 – The Larval Stage:

The difference between a worker and the queen bee is made three days after the egg transforms into larvae and six days after the egg is laid in the beehive. For the first three days, "royal jelly" (Royal jelly is a honey bee secretion that is used in the nutrition of larvae and adult queens. It is secreted from the glands in the hypopharynx of nurse bees-a kind of worker bees) is fed to all the larvae, i.e., the female bees, the workers as well as the drone bees. Later on, the royal jelly is fed only to the female larvae, which is destined to become a queen bee. Finally, the worker bees cover the top of the cell with beeswax to protect and facilitate the transformation of the larvae into a pupa.

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Stage 3 – The Pupal Stage

This is the 3rd stage in the cycle of a bee. Here, the larva starts to build a cocoon around itself from self-woven silk. The larva from the inside slowly starts to develop parts like wings, head, thorax, legs, and abdomen as it comes to completion into its larva bee life cycle stages.

Stage 4 – The Adult Stage:

Once the pupa is matured, the new adult bee chews its way out of the closed-cell. The queen bee takes approximately 16 days from the egg stage to form into an adult. Queens are reared in specialized large queen cells which are specially constructed for queen larvae and have a vertical orientation. When the old queen dies or becomes weak, the workers will construct emergency cells known as supersedure queen cells, which are larger and project from the comb. Supersedure refers to the phenomenon where old and ailing queen is replaced by a new one. As the queen ages or ails, the output of queen substance pheromone is not produced. This signals workers to rear a new queen. The workers quickly detect the ailing queen or its inability to lay eggs and will then rear a new queen. The drone bees take 24 days to develop into an adult bee. Drones are genetically haploid males. They possess weak mouthparts and hence are not able to forage for nectar as well as pollen themselves and thus have to be fed and look after by the workers. Drones fertilize the queen by mating in nuptial flight, after which drone dies. The drones are usually expelled out from the hive and die of either cold or starvation. The queen stores sperms in small sac-like organ referred to as spermatheca located in the queen's abdomen. The worker bee takes around 18 to 22 days for its complete development. Figure 4.22 depicting the caste of honeybee**.**

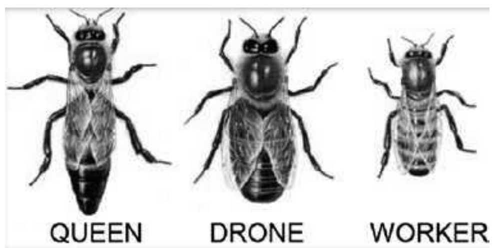

***Fig. 4.22** Caste of Honeybee*

A worker bee has a lifespan of around 6 weeks. The first half of a worker bee's life is spent in the hive attending to household chores, secreting wax and building hive, producing a highly nutritious royal-jelly, feeding the developing larvae and converting nectar into honey. In the latter part of life, they become foragers and collect nectar as well as pollen. Towards the end of their life, they become incapable to collect nectar as well as pollen and therefore become water-carriers. They eventually die in work and serves as an excellent example of selfless service for the society. Figure 4.23 is depicting the life cycle of *Apis sp*.

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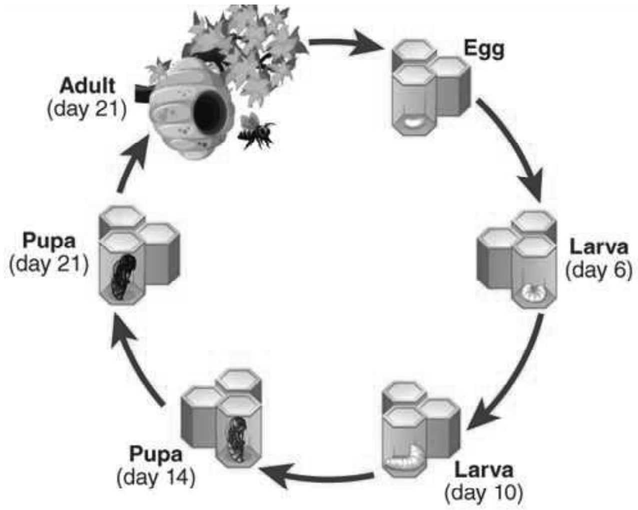

Fig. 4.23 *Life Cycle of Apis sp.*

Products of culturing Honey Bee

1. Honey

Honey making by bees is a specialized procedure in which the bees collect nectar from flowers. Nectar is a clear liquid composed of 80% water and sugars. The worker bees search for best quality flowers and collect nectar in their crop region and binds pollen on hind leg. After collecting both nectar as well as pollen, these flies return back to their hive and unload it into the cell. The workers in hive then begins digesting the raw nectar for approximately 30 minutes and regurgitate it into the cell. This is done several times to add enzymes as well as other materials into it. This honey is then placed in empty cells of honeycomb to bring the water content to less than 20%. They fan the honey with their wings to bring down the water contents. Once ripe, the cells of the honeycomb are sealed with the help of wax cap. Honey is a viscous fluid produced from the flower nectar by the bees. Commercially, it is the one of the most significant products of *apiculture* as it is a whole food composed of sugars, antibiotics, enzymes, acids as well as minerals. Honey is a rich source of energy as it has a high sugar content. It is used in the preparation of several *ayurvedic* and *unani* medicinal preparations. In severe cases of malnutrition, ulcers and impaired digestion, honey is recommended for regular consumption.

2. Pheromones

Chemical secretions or pheromones which are produced by the queen bee bind the colony together. Worker bee secrete chemical secretions or pheromones from Nasanov gland which are located inside the tip of abdomen. These pheromones help the workers to identify the members of their own colony when they group together or collect nectar or water. It is possible due to the fact that pheromone released by the bees of the same colony has a unique chemical composition. Whenever, a queen flies to mate, her pheromones attract all the drones. Another pheromone, known as the queen substance is licked by workers from the queen's body and passed on to other members of the hive. The primary function of the queen substance is to inhibit the ovaries of workers and renders

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them sterile. Another pheromone produced by the workers is alarm pheromone. The mandibular glands of workers release alarm pheromone. The primary function of this alarm pheromone is to alert the colony when it is threatened or attacked by a predator. Workers leave the sting on the body of victim which also produces a sting odor, which serves to attract other bees to the area for stinging.

3. Royal Jelly

Royal jelly is a secretion released from the hypopharyngeal glands of nurse-bees (a kind of worker bee only). Queen larva as well as the young workers feed on royal jelly. Royal jelly is milky in color and is composed of proteins, lipids, carbohydrates, minerals like iron, Sulphur, copper and silicon. Royal jelly increases the vitality as well as vigour in humans.

4. Beeswax

Beeswax is secreted as a liquid however it gets solidified when exposed to air. Scales are formed after solidification which is removed by the hive-bees for building the comb. Even though, the wax is white in color, however, the shade varies depending on the pollen pigments. It is primarily used in the candle industry. Other major places where the bees wax is essential are for making products like creams, ointments, capsules, deodorants, varnish, shoe polish, etc.

5. Propolis

Propolis is the resin-like exudate which is collected by honey bees from the trees. Propolis is used by honey bees for sealing the cracks as well as crevices. The characteristic property of propolis is its adhesiveness and hence mixed with Vaseline. Propolis also has burn healing property and used for preparing ointments that treats cuts, wounds, etc.

6. Bee Venom

Bee venom is a characteristic secretion used by the worker bees as a defense mechanism. Bee venom is composed of active chemicals such as histamine, hydrochloric acid, formic acid, calcium, Sulphur, apamine, etc. Commercially, it can be obtained via electric shock. The hives are connected to a live circuit of 12-15 volts. Whenever, the honey bees get in touch with the wire they receive the shock which irritates them and they react by depositing venom. Bee venom is injected into patients suffering from rheumatism. They cannot be cured by any other method. It also helps in curing neuralgia, endoarthritis, necrosis, etc.

Check Your Progress

5. Which honey bee is considered to be the most primitive honey bee species?
6. What are pheromones?
7. What is Propolis?

4.4 LAC CULTURE

The word *lac* is derived from the Sanskrit word *lākshā*, which represents the number 100,000. It was used for both the lac insect (because of their enormous number) and the scarlet resinous secretion it produces. This resin has been used for making traditional and tribal bangles and still used as sealing wax by the India Post. It is also used as wood finish, skin cosmetic and dye for wool and silk in ancient India and neighbouring areas. Lac resin was once imported in sizeable quantity into Europe from India along with Eastern woods. Lac is secreted over the bodies by two families of insects belonging to order Hemiptera, namely, Lacciferidae and Tachardinidae. The function of the secreted lac is to protect the insect. **Lac Insect** belongs to ***Laccifer*** of superfamily Coccoidea of order Hemiptera. In total, 22 species have been recorded under the genus ***Laccifer*** in Indian subcontinent. India is the biggest producer of lac in the world. India accounts for approximately 65% of the world's total output in which Bihar and Jharkhand contributes nearly 40% of India's total production of lac. The classification of *Laccifer lacca*:

Phylum — Arthropoda

Class — Insecta

Order — Hemiptera

Super-family — Coccoidae

Family — Lacciferidae

Genus — *Laccifer*

Species — *lacca*

Host Plants

Laccifer lacca can be cultivated on either cultivated or wild host plants. The host plants of *Laccifer lacca* are as follows:-

- In India the most common host plants are:
  - o Dhak (*Butea monosperma*)
  - o Ber (*Ziziphus mauritiana*)
  - o Kusum (*Schleichera oleosa*) (reported to give the best quality and yield)
- In Thailand the most common host plants are
  - o Rain tree (*Albizia saman*)
  - o Pigeon pea (*Cajanus cajan*)
- In China the common host plants include
  - o Pigeon pea (*[Cajanus cajan*)
  - o Hibiscus species
- In Mexico
  - o Barbados nut (*Jatropha curcas*)

Life Cycle of Lac Insect

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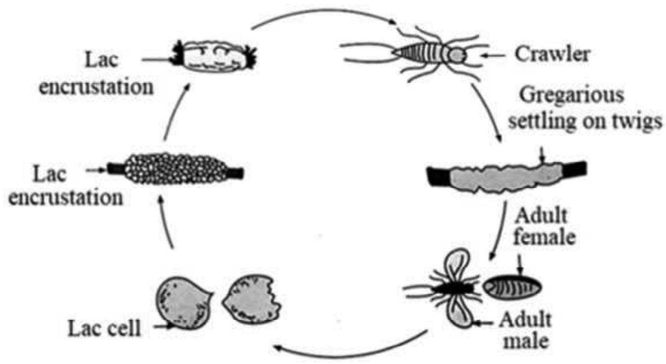
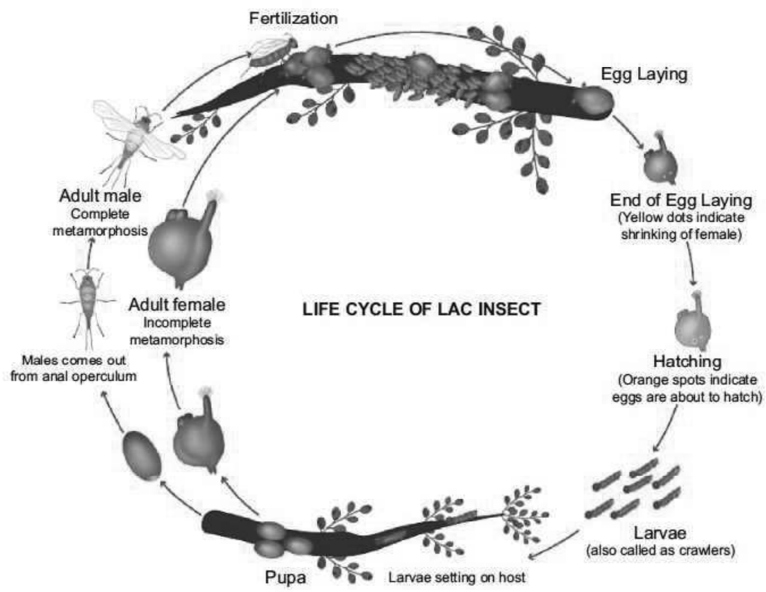
The lac insects show exhibit sexual dimorphism, i.e., morphological differences in the male and female insect. Female insect is viviparous. It produces approximately 1000 nymphs. Female is deep red in colour with black eyes. The larvae settle down on a suitable place of the host plant gregariously. A day or two after the settlement, the larvae start secreting lac all around the body except on the rostrum, spiracles as well as on the tip of abdomen. Thus, the larva gets encased in a cell of lac which slowly increases in size as the size of the insect keeps on growing. The insect moults twice before reaching maturity. The male larvae produce elongated lac cells while the females produce oval cells. After the first moult, larvae lose their legs, antennae as well as eyes and attain a bag-like structure. After the third moult, the larvae pass on to a pseudo-pupal stage. Males emerge and copulate with the females and die. The female larvae never regain appendages and continue to remain under the lac cell, become adults and reproduce. As the lac insects remain close together, lac secretion from adjacent cells coalesces with each other and forms a continuous encrustation on the tree branch. Figure 4.24 depicting the life cycle of lac insect.



(a)



(b)

***Fig.4.24** Life Cycle of Lac Insect*

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Lac Cultivation

Lac cultivation begins with Culturing farmer inoculating a host plant with a female cell where eggs are ready to hatch. The first instar larvae infest the host plant as soon as it emerges out of the egg. After locating the suitable spots for feeding, the larvae start secreting the resinous material around their body. At the beginning, this material appears to be shiny and hardens when it comes in contact with air. The lac casing is thus around the body of the larva and the twig on which it is feeding. Many lac cells of nearby larvae fuse together, and a lac encrustation is formed. This is the lac that a lac culturist is interested in. Figure 4.25 is depicting the heavy encrustation.

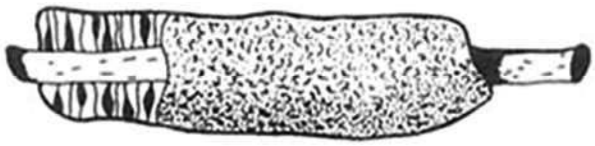

Fig. 4.25 *Heavy Encrustation*

The steps of lac cultivation are as follows:-

1. **Inoculation**: the term inoculation here refers to the introduction of lac insects to the host plant. Inoculation can be done in natural way without any human interference or artificially too.
2. **Cultivation:** It involves cultivating the host plants.
3. **Lac Crop**: the life cycle of lac insects is of six months and thus two crops in a year are regular. There can be four lac crops as lac insects behave differently on Kusum and non-Kusum host plants.
4. **Harvesting and Extraction of Lac**:
   a) The twigs with thick encrustations are cut and removed from the site. This is **stick lac**
   b) Then the lac cells are scraped from the twig, and the lac is the **granular lac**.
   c) If the cutting and scraping is done before swarming, it is **'Ari lac**', and if it is done after swarming, it is '**Phunki lac**'
   d) The scraped lac is washed thoroughly with water.
   e) Drying and bleaching of lac are done by exposing it to sunlight.
   f) Lac granules are melted in a pot over an open charcoal fire.
   g) The molten lac is then spread in the form of sheets.
   h) The sheets are dried, broken into pieces and sold in the market as flakes.

Processing Of Lac

The first step in the processing of lac involves removal of lac encrustations from the twigs of host plants by scraping. The raw lac thus obtained is referred to as scraped lac or stick lac. Further, the **Stick lac** is crushed into small grains, sieved, washed with mild alkaline water and dried. This semi-refined lac product is now

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known as **seed lac** or **grainlac** or **Chowrie**. Subsequently, seed lac is refined by a system of hot melting, filtration and stretching into thin sheets. These thin sheets are further broken into brittle flakes known as **shellac**. Alternatively, the purified lac resin can also be in the form of circular discs known as button lac. If a specific solvent process is utilized to purify the raw lac, de-waxed, decolorized lac can be obtained as the end product. The normally amber coloured resin can also be bleached with sodium hypochlorite to obtain bleached lac, which is white in colour. Bleached lac has specialised demand for coating medicinal tablets, confectioneries etc.

Types of Lac

Lac is the only known commercial resin of animal origin. It is a resinous material secreted by the lac insects. Special glands called lac glands are present in the skin of the larvae and the adults. Lac is a mixture of several substances, but resin is the main constituent. It is thought to be a polyester of straight chain of complex fatty acids. It is also supposed to contain other substance like sugar, proteins, soluble salts, debris of lac insect and some woody material. Depending on the host plant, lac is of two types:

1. **Kusumi Lac**: insects are reared on Kusum plants, and lac is harvested from these plants.
2. **Ranjeeni Lac**: when the lac insects are reared on non-Kusum plants, the lac is known as Ranjeeni lac.

Inoculation	Emergence of Male	Crop Reaped	Rise of swarming larvae
Ranjeeni (non-Kusumi) Crop			
Kataki (June-July)	Aug	October-November	October-November
Baisakhi (October-November)	February-March	April-May	June-July
Kusumi Crop			
Aghani (June-July)	September	December-January	January-February
Jethoi (January)	March-April	June-July	June-July

Natural Enemies of Lac

There are two kind of natural insect enemies**:**

(a) Natural Predators of Lac insect: The predators are more serious when compared to parasites and may cause damage up to 30-35 per cent to the cells in a crop. *Eublemma amabilis* and *Pseudohypatopa pulverea* are the most destructive to lac insects and are in regular occurrence but their incidence may vary from season to season, place to place and crop to crop.

(b) **Natural Parasites of Lac insect:** All parasites causing damage to lac insect belong to the Order Hymenoptera of class Insecta. *Tachardiaephagus tachardiae* and *Tetrastichus purpureus* are the most abundant lac associated parasites. They lay their eggs in the lac cells and the grubs (larvae) after hatching start to feed on the lac insect within its cell.

Parasite and Predators of Lac insect are shown in table 4.1.

Table 4.1 *Parasite and Predators of Lac Insect*

Parasite of lac insects	Family	Predators of lac insects	Family
Anicetus dodonia	Encyrtidae	*Eublemma amabilis*	Noctuidae
Atropates hautefeuilli	Encyrtidae	*E. coccidiphaga*	Noctuidae
Aphrastobracon flavipennis	Encyrtidae	*E. cretacea*	Noctuidae
Bracon greeni	Encyrtidae	*E. scitula*	Noctuidae
Campyloneurus indicus	Encyrtidae	*Pseudohypatopa pulverea*	Blastobasidae
Coccophagus tchirchii	Aphelinidae	*Catablemma sumbavensis*	Blastobasidae
Erencyrtus dewitzi	Encyrtidae	*Cryptoblabes ephestialis*	Blastobasidae
Eupelmus tachardiae	Eupelmidae	*Phroderces falcatella*	Cosmopterygidae
Eurymyiocnema aphelinoides	Aphelinidae	*Lacciferophaga yunnanea*	Momphidae
Lyka lacca	Encyrtidae	*Chrysopa madestes*	Chrysopidae
Marietta javensis	Aphelinidae	*C. lacciperda*	Chrysopidae
Parageniaspis indicus	Encyrtidae	*Berginus maindroni*	Mycetophagidae
Parechthrodryinus clavicornis	Encyrtidae	*Silvanus iyeri*	Cucujidae
Protyndarichus submettalicus	Encyrtidae	*Tribolium ferrugineum*	Tenebrionidae
Tachardiaephagus tachardiae	Encyrtidae	*Phyllodromia humbertiana*	Blattellidae
Teachardiobius nigricans	Encyrtidae	*Ishonoptera fulvastrata*	Blattellidae
Aprostocetus (Tetrastichus) purpureus	Eulophidae	*Dolichoderus thoracicus*	Formicidae

Prevention and Control of Insect Enemies

(a) For inoculation purpose, Parasite as well as predator- free brood lac must be used.

(b) Inoculated brood bundles must be kept on the host tree for a limited period only.

(d) Phunki (empty brood lac sticks) must be removed from the inoculated trees in 2-3 weeks' time.

(e) All lac cut from the tree as well all phunki brood lac (after use as brood lac) not required for brood purpose must be scraped or fumigated at once.

(f) Cultivation of Kusmi strain of lac should be avoided in predominantly Rangeeni area and vice versa.

(g) Mechanical control involves using 60 mesh synthetic netting (brood bag) to enclose brood lac for inoculation purposes. By this strategy, infestation of the enemy can be reduced drastically. The larvae emerging out from the pores of the net can settle easily on the host plant whereas the adult predator enemies cannot escape out of the brood bags and get easily trapped within the mesh. This helps in preventing the egg laying by the predator moth on the new crop.

(h) Chemical control involves applying 0.05% endosulfan at 30-35 days stage of crop. Research has proved it to be the most effective dose of insecticide without having any adverse effect on the economic aspects of the lac insect.

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(i) Microbial control involves use of bio-pesticide, Thuricide (Bacillus thuringiensis) at 30-35 days stage of crop.

(j) Biological control involves using two ant predators namely *Camponotus compresus* and *Solenopsis geminate rufa*, as the most important and promising for biological control of predator enemies of lac in field condition.

Microbial Flora Associated with Lac Insects

Bacteria as well as fungi are widely associated with the lac insects. Research revealed that four bacterial species namely *Micrococcus varians. M. conglomerates, Clostridium sp. and Bacillus subtilis*, are found to be permanently associated with different stages of lac insects. These bacteria are known to be good for the yield of lac especially during the rainy season. On the contrary, association of fungi with lac insect is not always considered beneficial as the fungal infection could kill the lac insect by inhibiting respiration, by hindering mating process, by blocking emergence of larva, by affecting the efficiency of host etc. Three species of fungi namely *Aspergillus awamori, Aspergillus terricola and Penicillium citrinum* are known to cause maximum loss in lac crop. Application of fungicides, Bavistin (carbendazim 0.05%) and Dithane M-45 (mancozeb, 0.18%) by both dipping of brood lac before inoculation and spraying on standing crop gives significantly better yield of lac.

Application of Lac

The use of lac can be summarized as follows:

- Lac resin is used in large scale commercial activities like food processing industry; cosmetics and toiletries industry; varnish and printing industry; coating of fruits and vegetables; electrical industry; leather industry; adhesive industry; pharmaceutical industry; perfumery industry; miscellaneous applications.
- Lac dye (erythrolaccin) has been used in India as a skin cosmetic and dye for wool and silk.
- In China, it is a traditional dye used for leather goods.
- Lac dye is used in medicine to protect liver and to fight obesity.
- Lac is used in food, confectionery, beverages industry as well as textile industry.
- Lac wax is used in polishes for shoe, floor, car polishes etc.
- Lac dye is used in electric insulations, lamination of papers, hat proofing and coating of pictures and fossils.
- Lac is used for manufacture of tailors chalks, crayons, bottle sealers, lipsticks, enamels, printing inks, gramophone records and in fireworks.

Check Your Progress

8. Lac Insect belongs to which superfamily?
9. Which are the two types of lac?
10. What is the use of lac resin?

4.5 INSECTS AND POLLINATION

Pollination refers to the transfer of pollen from a male part of a plant to a female part of a plant, later enabling fertilization and the production of seeds, by a pollinating agent. The most common pollinating agents are animals such as insects, birds, and bats; water; wind; and even plants themselves, when self-pollination occurs within a closed flower.

Entomophily refers to the form of pollination whereby pollen is distributed by insects. Invertebrates such as honey bees, moths, butterflies, wasps, ants, midges and beetles are generally accountable for pollinating a huge majority of the world's flowering plants. Insects and flowers both benefit from their specialized symbiotic relationships; plants are pollinated while insects obtain valuable sources of food.

Plants that are pollinated by insects shows unique adaptations which helps the insects to get attracted towards them. A few adaptations are as follows: -

- Brightly coloured flowers
- Flowers having bold or highly visible patterns
- Strong fragrance
- A few plants release insect attracting pheromones. Plants in this category are referred to as entomophilous plants.

Insect pollinators

A few insect pollinators are discussed below:

1. Honey Bees

Honey bees are the most important pollinator of many garden plants as well as commercial fruit trees. Flowers pollinated by bees remain open during the day time. Bees are attracted to brightly coloured flowers having a strong fragrance/ aroma and possess a tubular body with the presence of nectar guide. A nectar guide refers to the bold and highly visible pattern/regions on the flower petals that guide bees to the centre of the flower, thus making the process of pollination highly efficient. As bees cannot see the red color, they pollinate flowers having the shades of blue, yellow, or other colors. Bees and flowers exhibit symbiotic relationship. Bees visit flowers to obtain rich pollen or nectar for their survival and energy needs. While, they are sucking nectar from flowers, pollen grains stick to the bee's fuzzy hair. When the bee visits other flower for getting nectar, few pollen grains get transferred to the second flower. The significance of honey bees can be seen from the fact that several flowers will remain unpollinated, failing to bear seeds if honeybees disappear from the earth. The impact of disappearance of honey bees on commercial fruit growers could be devastating.

2. Bumble Bees

Bumble bees are significant pollinators of wild flowering plants as well as agricultural crops. Bumble bees are able to fly in cooler temperatures and lower light levels when compared to other bees. They possess rounded, fuzzy bodies and have the ability to perform 'buzz pollination,' This type of pollination involves grasping a flower in jaws and vibrating the wing muscles to dislodge the collected pollen grain. Plant species like wildflowers and crops such as tomatoes, peppers and cranberries are pollinated by buzz pollination.

3. Butterflies and Moths

Butterflies, like monarch butterflies, pollinate several garden flowers as well as wildflowers, which are usually found in clusters. Flowers pollinated by moths as well as butterflies are generally bright colored and have a very strong fragrance/ scent. The pollen is picked up by butterflies and carried on its limbs. However, moth pollinate flowers during the late afternoon and night time. The flowers pollinated by moths are generally flat, pale or white in color. For instance: - yucca plant is pollinated by yucca moth. Insect and flower exhibit the symbiotic relationship and both get benefitted from the relationship. The moth deposits pollen on the sticky stigma of the flower for fertilization to occur later on. The female moth also deposits eggs. As the eggs hatches to larva, they get food from the flower as well as developing seeds. Also, the adult gets nectar from flower.

4. Wasps

Wasps are generally smooth-bodied and do not actively collect pollen. Wasp lacks the branched, pollen-trapping hairs found on the body of most bees; hence they are minor pollinators of most plants. However, they do pollinate many species of figs.

5. Flies

Flies belongs to the order Diptera of insects. Even though, few flies are known to be crop pests as well as carriers of some serious disease, many are beneficial too. Flies are generalised foragers with no nests to provision and also due to their sparsely haired bodies, they don't get much acknowledgement as substantial pollinators. Though, they can be significant pollinators for few specific plants. Flies are attracted to dull brown and purple flowers that have an odor of decaying meat or a smell of rotting fish. They are found on the corpse flower or voodoo lily (*Amorphophallus*), dragon arum (*Dracunculus*), and carrion flower *(Stapleia, Rafflesia*). The nectar provides energy while the pollen provides protein.

6. Beetles

Beetles represents one of the most diverse group of organisms in the entire world. Beetles exhibits diversity in shape, color as well as their ecological role in the environment. Beetles predominantly pollinate flowers like magnolias and water lilies.

Check Your Progress

11. Define pollination.
12. What is Entomophily?
13. Which insects are generally accountable for pollinating majority of the world's flowering plants?
14. What do you understand by buzz pollination?

4.6 INSECTS AS HUMAN FOOD FOR FUTURE

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Entomophagy describes a feeding behaviour that includes eating insects. Besides, non-human creatures, the term can also refer to the practice of eating insects among humans. The idea of essentially eating insects may sound repulsive to many, however, edible insects, which have been a part of several traditional communities all over the world, are now in the attention for their capability to Curb Greenhouse Gas (GHG) emissions. The United Nations (UN), in its special report on climate change and land, released in August 2019, has mentioned that insects are an environment-friendly substitute to meat. At the same time, the Food and Agriculture Organization (FAO) has also said that insects will play an essential role in providing food security for the ever-increasing population that is slated to reach 9 billion in the next three decades. Insects as food or edible insects are insect species used for human consumption, e.g., whole or as an ingredient in processed food products such as burger patties, pasta, or snacks. Figure 4.26 depicting the whole, fried edible insects as street food in Germany.

Fig.4.26 *Fried Edible Insects as Street Food in Germany*

Frequently consumed insect species.

Approximately, 1,000 to 2,000 edible insect species have been consumed globally. These edible insect species comprise of 235 butterflies and moths, 344 beetles, 313 ants, bees and wasps, 239 grasshoppers, crickets and cockroaches, 39 termites, and 20 dragonflies, as well as cicadas. The type of insect species consumed in a particular region depends upon the difference in culture, tradition, climatic conditions, ecosystem, environmental conditions, etc.

Table 4.2 *Consumption Rate of Different Insects by Human Population*

Order of insect	Common name	Consumption rate worldwide by human population (%)
Coleoptera	Beetles	31
Lepidoptera	Butterflies, moths	18
Hymenoptera	Bees, wasps, ants	14
Orthoptera	Grasshoppers, locusts, crickets	13
Hemiptera	Cicadas, leafhoppers, planthoppers	10

NOTES

The consumption rate of different edible insects by human population are listed in Table 4.2.

In India, as many as 303 insect species are consumed by tribal communities in 10 states. Khajuri poka or date palm worm is a delicacy in Odisha's Rayagada district, inhabited by Khond and Sora tribes. The table depicts the list of top five insect orders consumed by humans worldwide, retrieved from *Edible Insects: Future Prospects for Food and Feed Security* by Arnold van Huis, Joost Van Itterbeeck, Harmke Klunder, Esther Mertens, Afton Halloran, Giulia Muir and Paul Vantomme. Figure 4.27 depicting that over 300 insect species are consumed by tribal communities in 10 states of India.

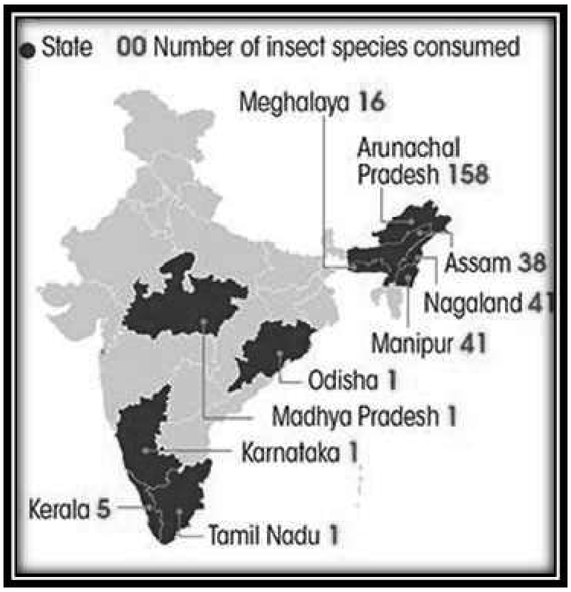

Fig. 4.27 *Insect Species are Consumed by Tribal Communities in India.*

Source: Diversity of Edible Insects and Practices of Entomophagy in India, 2014.

Edible Insects for Industrialized Mass Production

Due to its nutritional efficiency and other advantages, commercial exploitation of edible insects is on the rise. "More and more start-ups are engaging in the industry. Some of them are attracting large sums of money, which shows that investors are becoming aware of the business opportunities," said Avan Huis, professor of tropical entomology at Wageningen University in the Netherlands, and author of a 2019 paper titled *Insects as food and feed, a new emerging agricultural sector: a review*. Insects have been processed into a non recognizable form like that of powders or flour. Stakeholders like Policymakers, academics and large-scale insect food producers like *Entomofarms* in Canada, *Aspire Food Group* in the United States, *Protifarm* and *Protix* in the Netherlands, and *Bühler Group* in Switzerland, lays emphasis on seven insects species which are suitable for human consumption as well as for industrialized mass production.

- Mealworms (*Tenebrio molitor*) as larvae
- Lesser mealworms (*Alphitobius diaperinus*) as larvae, mostly marketed under the term *buffalo worms*.
- House cricket (*Acheta domesticus*)
- Tropical house cricket (*Gryllodes sigillatus*)
- European migratory locust (*Locusta migratoria*)
- Black soldier fly (*Hermetia illucens*)
- Housefly (*Musca domestica*)

Nutritional Profile of Edible Insect

Edible insects are being promoted as a food source for three primary reasons namely: environmental benefits, nutritional value and livelihood opportunities. Edible insects have a high feed conversion efficiency (the quantity of feed required to increase the weight of a livestock by a kg) as they are cold-blooded.

According to FAO, insects can convert approximately 2 kg of feed into 1 kg of insect mass, while cattle need somewhere around 8 kg of feed for 1 kg of body weight gain. Insect farming is also resource efficient. As stated by the UN report "A gramme (g) of beef protein requires about 14 times more land and five times as much water to produce compared with a gramme of mealworm protein,". The production of GHGs (greenhouse gases) by most insects is lower as compared to that of conventional livestock. For instance, pigs produce 10 to 100 times more GHG per kg of weight as compared to mealworms. The nutrition which is obtained from insect as well as beef is also comparable — cricket contains approximately 205 g of protein and 68 g of fat per kg, whereas ground beef is composed of around 256 g of protein and a disturbing 187 g of fat per kg. Further, Insects like crickets are a rich source of protein and their protein content is higher when compared to plant based protein rich food like soybeans. Crickets are also very efficient in terms of nutrients. For instance- for every 100 grams of substance crickets contain nearly 12.9 grams of protein, 121 calories, and 5.5 grams of fat. Beef contains more protein containing 23.5 grams in 100 grams of substance, but also has roughly triple the calories and four times the amount of fat as crickets does in 100 grams.

Further, insects are a rich source of minerals and vitamins. For instance: Crickets are very good source of calcium, termites are rich in iron, and the silkworm moth larvae can easily fulfil the daily requirement of copper and riboflavin in human beings. Further, it has been observed that Locusts contain around 8 to 20 milligrams of iron for every 100 grams of raw locust, on the contrary, meat-based food like Beef contains approximately 6 milligrams of iron in the same amount of meat. A few research studies indicate that eating bees can boost the libido (sex drive). Thus, from the above comparison, it can be easily understood that insects are nutrient-efficient when compared to other meat sources. Figure 4.28 is depicting the comparison between nutritional value of meat-based food (Beef) and edible insect.

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Table 4.3 Comparison of Nutritional Value of Edible Insects

Nutritional value per 100 g	Mealworms (*Tenebrio molitor*)	Buffalo worms (*Alphitobius diaperinus*)	House crickets (*Acheta domesticus*)	Migratory locust (*Locusta migratoria*)
Energy	550 kcal / 2303 KJ	484 kcal/ 2027 KJ	458 kcal/ 1918 KJ	559 kcal/ 2341 KJ
Fat Of which saturated fatty acids	37,2 g 9 g	24,7 g 8 g	18,5 g 7 g	38,1 g 13,1 g
Carbohydrates Of which sugars	5,4 g 0 g	6,7 g 0 g	0 g 0 g	1,1 g 0 g
Protein	45,1 g	56,2 g	69,1 g	48,2 g
Salt	0,37 g	0,38 g	1,03 g	0,43 g

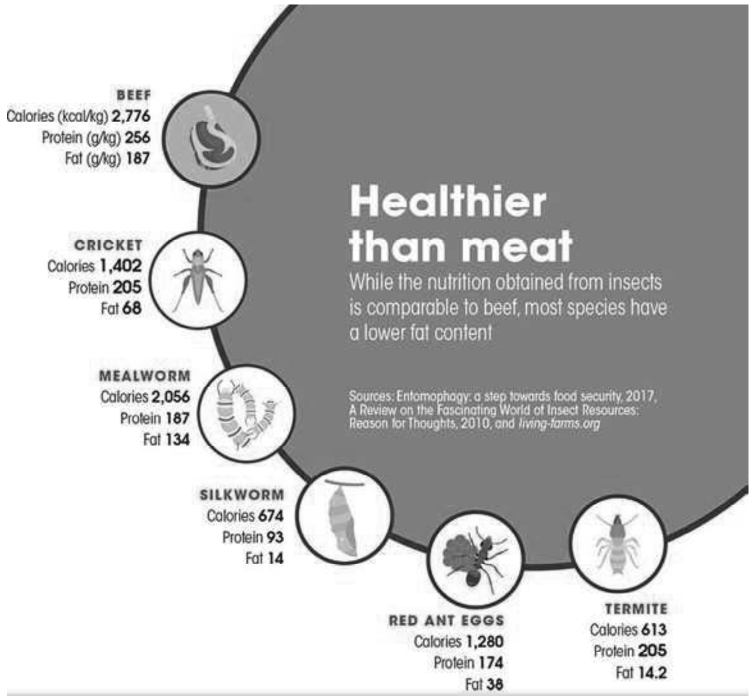

Fig. 4.28 *Comparison between Nutritional Value of Meat-Based Food (Beef) and Edible Insect*

Source of Figure- Entomophagy: A step towards food security, 2017. A review on the fascinating world of insect resources, reasons for thought, 2010, and living farms.org

Insect Farming

Edible insects (insects that are fit for human consumption) are raised as livestock in specialized insect farms. In North American and other European countries like Netherlands or Belgium, insects are produced under strict food law and hygiene standard for human consumption. Based on the insect species, the conditions such as temperature, humidity, feed, water sources, housing varies. The edible insects are raised from eggs to larvae status (mealworms, lesser mealworms) or to their mature form (crickets, locusts), and then killed, in industrialized insect farms by lowering down the temperature. After killing, these edible insects are freeze-dried and packed whole, or grounded to form insect powder (insect flour), to be processed in other food products like bakery products, or snacks.

As we have mentioned in the above discussion that insects are nutritious food and highly digestible as they are rich in dietary fibre too. Besides this, insects are also selected for ease of rearing by the producer. This includes susceptibility to disease, efficiency of feed conversion, developmental rate as well as generational turnover. Figure 4.29 depicting the insect breeding for human consumption.

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Fig. 4.29 *Insect Breeding for Human Consumption*

Insect Food Products

In North America, Canada, and the EU, following processed food products are produced:

- *Insect flour*: Grounded, freeze-dried insects (For instance- cricket flour).
- *Insect burger*: Insect burger is a kind of Hamburger patties made from insect powder / insect flour (such patties are made majorly from mealworms or from house cricket) and further ingredients.
- *Insect fitness bars*: These are Protein rich bars composed of insect powder (mostly house crickets).
- *Insect pasta*: Insect Pasta is made of wheat flour, fortified with insect flour (for instance- house crickets or mealworms).
- *Insect bread* (Finnish *Sirkkaleipä*): Bread baked with insect flour (majorly house crickets).
- *Insect snacks*: Crisps, flips or small snacks (*bites*) composed of insect powder as well as other ingredients.
- Food and beverages companies like the Australian brewery Bentspoke Brewing Co and the South-African startup Gourmet Grubb even introduced *insect-based beer*, a milk alternative, as well as *insect ice cream*.
- Insect energy bar made with processed crickets as primary ingredient
- Insect snacks are composed of cricket flour
- Insect snacks (*bites*) with cultivated cricket flour and oat

Regulation and Authorization

Switzerland has approved the following insect species as food on 1 May 2017:

- *Acheta domesticus* (House cricket)

- *Locusta migratoria* (European locust)
- *Tenebrio molitor* as larvae (Mealworms)

EU (European Union)

NOTES

- In the European Union, edible insects – either whole or in parts, like legs, wings, or head region of the insects – fall within the definition of novel food, given by the European Commission.
- Dossiers for several insect species are presently under review by the European Food Safety Authority (EFSA).
- European Food Safety Authority (EFSA) published a first risk profile for the house cricket as edible insect or food source on August 2018.
- The yellow mealworm is safe for human consumption according to a risk assessment published by European Food Safety Authority (EFSA) on 13 January 2021,
- European Food Safety Authority (EFSA) published another scientific opinion stating that migratory locust in frozen, dried or grounded state is safe for human consumption on 2 July 2021, EFSA.
- European Food Safety Authority (EFSA) published a safety assessment with view to house crickets (Acheta domesticus) stating that frozen and dried formulations from whole house crickets are safe for consumption on August 17, 2021, EFSA.
- With the *Commission Implementing Regulation (EU) 2021/882 of 1 June 2021*, the European Commission authorized the following edible insect as novel food in the EU:
- Dried Tenebrio molitor larvae (*mealworms*).
- The regulation came into force 20 days after its publication on 22 June 2021.

Challenges and Safety Concerns

Despite, the potential of insects being the nutritious rich food, there are certain challenges as well as safety concerns associated with the mass production of edible insects.

- Lack of technology, funds as well as skilled labour is the primary concern of insect farming/industry.
- The machinery would have to house proper enclosure for each life cycle of the insect and the temperature control as that is key for insect development.
- Further, as this is still a developing food product, so the industry has to take into consideration the shelf life of insects in comparison to animal products as that can have some food safety concerns.
- Further, it should be kept in mind that Insects can accumulate accumulating potential hazards like contaminants, toxic substance, heavy metals, pesticides, insecticides, pathogens, allergens, etc., and they are also susceptible to several bacterial, viral or fungal infections besides pest attack.

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- In the table 4.4 below, the data is combined from two studies published in Comprehensive Reviews in Food Science and Food Safety, and summarized the potential hazards of the top five insect species consumed by humans.

Table 4.4 *Potential Hazards of Top Five Insect Species Consumed by Humans*

Insect order	Common name	Hazard category	Potential hazard
Coleoptera	Beetle	Chemical	Hormones
			Cyanogentic substances
			Heavy metal contamination
Lepidoptera	Silkworm	Allergic	
		Chemical	Thiaminase
	Honeycomb moth	Microbial	High bacterial count
		Chemical	Cyanogentic substances
Hymenoptera	Ant	Chemical	Antinutritional factors (tannin, phytate)
Orthoptera	House cricket	Microbial	High bacterial count
Hemiptera		Parasitical	Chagas disease
Diptera	Black soldier fly	Parasitical	Myiasis

- However, Hazards mentioned above on the table can be controlled by various ways.
- Allergic hazard can be labelled on the package to avoid consumption by allergy susceptible consumers.
- Further, selective farming can be used to lessen the chemical hazard, while microbial and parasitical hazard can be controlled by cooking processes.

Awareness

The World Edible Insect Day is celebrated on 23 October. This day was first introduced by Belgian entrepreneur Chris Derudder in 2015 in order to raise awareness globally for the consumption of edible insects, with a focus on Europe, North America, and Australia. Edible insects offer a lot of potential in countries like India, which are already farming bees, silk moth larvae and lacquer-scale insects.

Check Your Progress

15. Define entomophagy.
16. Why edible insects are being promoted as a food source?
17. What is insect farming?
18. When the world edible insect day is celebrated?

4.7 ECOLOGICAL FACTORS AFFECTING THE POPULATION AND DEVELOPMENT OF INSECTS

Ecological factor or eco factor is any factor, abiotic or biotic, that influences living organisms. Abiotic factors include ambient temperature, amount of sunlight, and pH of the water, soil in which an organism lives. Biotic factors would include the availability of food organisms and the presence of biological specificity, competitors, predators, and parasites. The sum total of all ecological factors which affect the population and development of insects can be grouped into four categories namely:

1. Physical factors
2. Nutritional factors
3. Host associated factors
4. Biotic factors

1. Physical Factors- In this section, we shall discuss the physical factors affecting the survival, growth, development and reproductive potential of insects.

(a) Temperature

Insects are poikilothermic; hence they do not have any mechanism to regulate the body temperature. The body temperature depends on environmental factors. Normal physiological and metabolic life activities go on smoothly at a specific temperature (or) at a specific range of temperature. This is called the optimum temperature. Insects survive, thrives, grow and reproduce comfortably at this temperature. The rate of chemical reaction within tissues is modified by temperature. Metabolic processes are influenced by temperature and increase with it upto a maximum and suddenly decline at the upper lethal temperature. The upper lethal limit is 40-50^{o}C (even upto 60^{o}C survival in some stored product insects) and lower lethal limit is below freezing point. At low temperature (winter), insect takes more days to complete a stage (larval or pupal stage). However, at high temperature (summer) it takes less time to complete a stage. A few insects, when exposed to extremes of temperature undergo - Aestivation (during summer) or Hibernation (during winter). During this period, there is a temporary developmental arrest known as diapause stage in which all metabolic and physiological activities are suspended. When temperature is favorable, they resume activity. Eggs undergo aestivation in summer. Larva, pupa commonly undergo hibernation in winter. Temperature is an important factor in the life history of the insects. It influences:-

- The rate of development or number of generation passed in insects. The number of generations passed through during a year is directly dependent on the ambient temperature. For instance:- in sugarcane stem borer, *Chilo infuscatellus*, the larval period increases over 16-24 days in summer and 141-171 days in winter.
- Temperature also influences the fecundity and rate of egg production. For instance:-Grasshopper lays 20-30 times more eggs at 32^{o}C as compared

to 22°C. Similarly, Cabbage Diamond blackmoth lay more number of eggs at 18° C (larval temperature) than 22°C. Other instance is of bed-bug, where oviposition is inhibited at 8-10 degree Celsius.

- Further, temperature influences the rate of migration as well as dispersal of insect. In locust, *Schistioceva gregaria*, swarm migration occurs at 17°C to 20°C.

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(b) Moisture/Humidity

Moisture/relative humidity is required for metabolic reactions and transportation of salts in insects. Lack of moisture leads to dehydration or death of insects whereas excessive moisture can be harmful in following ways: -

- It affects the normal development as well as activity of insects.
- It encourages the disease-causing pathogens.

Termites are a group of insects for which atmospheric humidity is an important ecological factor. Termites prefers a relative high humidity of 90-95%. They usually move towards a zone of high humidity, when subjected to the slightest desiccation. Further, White halo fungus - *Verticillium lecanii* or coffee green scale *Coccus viridis* requires high relative humidity for their multiplication as well as transmission. Presence of a wax layer of cuticle in insects prevents the loss of water. Further, several insects exhibit morphological, physiological as well as other adaptations that prevent loss of moisture.

(c) Light

Light is one of the most crucial ecological factors affecting many aspects of the insect life. A lot of vital phenomena of the insect biology like feeding, growth, development, diapause, survival and ethology are greatly affected by light. The following properties of light influence insect life

- Intensity and illumination
- Quality or wavelength
- Duration or Photo period

Photoperiodism: Each daily cycle consists of a period of illumination followed by a period of darkness. Photo period influences induction of diapause (a resting stage) in most of the insects. For instance: in *Bombyx mori*, long day during embryonic development causes adult to lay eggs at diapause stage. Seasonal dimorphism has been observed in aphids due to change in photo period. Short day produces sexual forms whereas long day – produces asexual - Parthenogenetic forms. It has been observed that many species of insects are not equally active throughout the 24 hr of the day. A few insect species are active during the night time (nocturnal) whereas others are active during the day time (diurnal) and still other which are referred to as crepuscular (dusk active) are active mainly at dawn and dusk. Photoperiods also influence growth, metabolism and daily rhythm of activity (feeding, flying, mating and oviposition).

(d) Rainfall

Rainfall is must for normal emergence of adults from pupa of several insects like cutworms, *Helicoverpa armigiera and Spodoptetra litura*. However, excessive rainfall, causes white grubs to come aout of environment where they are subject to predation. Excess rainfall also control the population of aphids and Diamond blackmoth.

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(e) Water Current

Standing or stagnant water helps in the multiplication of insect like mosquitoes. On the other hand, running streams are preferred by black flies and caddish flies.

(f) Wind

Winds aids in dispersal of insects from one place to other. However, it interferes with the normal physiological processes of insects like feeding, mating and oviposition. For instance:-Aphids, mites (Eriophyid mites also) disperse through wind and Helicoverpa flies can fly upto 90 km with the aid of winds.

(g) Soil Type

Type of soil also plays an essential role in the multiplication of insects. For instance, wireworms can multiply easily even in heavy clay soil (poor drainage) with lesser drainage. On the other hand, white grubs and cut worm, requires loose sandy soil (light) with better drainage to multiply.

(h) Topographic Factors

Large areas like mountain, water bodies, sea etc. acts as physical barrier for the dispersal of insects.

2. Nutritional Factors

Insects are heterotrophic. They cannot synthesize their own food and hence depend on plants for nutritional requirements. The quantity as well as quality of food/ nutrition plays an essential role in survival, longevity, distribution, reproduction and speed of insect's development. The two major nutritional factors are:

(a) Quantity of Food

- Limited supply of food leads to intra-specific as well as inter-specific competition.
- Limited food supply also affects parasitoids and predators of insect's hosts.

(b) Quality of Food

- Quality of food depends upon the plants available.
- Crop varieties/species differ in nutritional status which also affects the growth, survival as well as development of insects

3. Host Plant Associated Factors

(a) Antixenosis

Antixenosis occurs when there is non-preference for the resistant plant compared to a susceptible one. Host plant not preferred by insects for feeding, oviposition or shelter due to morphological characters like thorns, wax, hairyness, etc., or done due to presence of some chemicals known as allelochemicals.

(b) Antibiosis

Antibiosis refers to adverse effect of the host plant on biology, i.e., growth, survival, development or reproduction of insects as well as of their progeny. It could occur due to absence of presence of toxic substance in host plant; due to absence of essential substances in the host plant or due to the presence of such enzymes in the host plant which affect the digestion of insects.

4. Biotic Factors

Biotic factors of the environment tend to modify the activities of insects. Individuals of a specific population not only interact with each other but also with other population. These interactions may be positive or negative depending on whether it produces beneficial or harmful effects on the interacting individual or population. Mutusalim, commensalisms are positive kind of interactions where the individuals starts adjusting with each other. On the other hand, negative interaction like competition, parasitism and predation affects the growth, survival as well as development of insects.

(a) Competition –Competition between the members of same species or different species occur for limited food, space, mate (between members of same species). Accordingly, competition can be inter-specific or intra-specific.

- **(I) Inter Specific Competition**: Inter-specific competition refers to the competition between individuals of the different species. This type of competition occurs mainly for limited food and space.
- **(II) Intra Specific Competition:** Intra-specific competition refers to the competition between the individuals of same species. This type of competition occurs for food, space as well as for mate.

(b) Parasites and Predators: Parasites like fungi, bacteria, protozoa, nematodes and various arthropods – predators like birds, mammals, reptiles, amphibians keep the insect population in check. Interaction between predator and prey are different from the parasite and host relationship.

The predator prey relationship comprises of the interactions that happen between two species and their subsequent effects on each other. In the predator prey relationship, one species feeds on the other species. The prey species represent the animal that gets killed whereas the predator species represent the animal that kills the prey. The predator prey relationship develops over time as many generations of each species interact. In doing so, they affect the success and survival of each other's species.

Similarly, the host parasite relationship is completely dependent on the interaction between two species. The interrelationship between the parasite and host populations incorporates with the infection level. Parasite lives comfortably inside or outside the host body. It extracts its nutritional requirement from the concerned host. The life cycle of parasitic insect includes specific host. Growth, survival as well as development of these parasitic insect depends upon the availability of specific host.

NOTES

Check Your Progress

19. List the four categories of factors, which affect the population and development of insects, can be grouped.
20. What do you understand by antibiosis?
21. For which group of insects, atmospheric humidity is an important ecological factor.

4.8 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Hoshomin, the Queen of China, introduced sericulture for the first time in China.
2. Trimoulters is the group of silkworms which moult three times during larval period.
3. Sericulture refers to the process of cultivating or growing silkworms
4. *Morus alba, M. indica, M. serrata* and *M.laevigata* are the four Indian species of mulberry.
5. *Apis Florea* is the smallest honey bee. It is considered to be the most primitive honey bee species.
6. Pheromones are chemical secretions which are produced by the queen bee, that bind the colony together.
7. Propolis is the resin-like exudate which is collected by honey bees from the trees. Propolis is used by honey bees for sealing the cracks as well as crevices.
8. Lac Insect belongs to Laccifer of superfamily Coccoidea of order Hemiptera.
9. The two types of lac are:
   - Kusumi Lac: insects are reared on Kusum plants, and lac is harvested from these plants.
   - Ranjeeni Lac: when the lac insects are reared on non-Kusum plants, the lac is known as Ranjeeni lac.
10. Lac resin is used in large scale commercial activities like food processing industry, cosmetics and toiletries industry, varnish and printing industry, coating of fruits and vegetables, electrical industry, leather industry, adhesive industry, pharmaceutical industry and perfumery industry.
11. Pollination refers to the transfer of pollen from a male part of a plant to a female part of a plant, later enabling fertilisation and the production of seeds, by a pollinating agent.
12. Entomophily refers to the form of pollination whereby pollen is distributed by insects.
13. Honey bees, moths, butterflies, wasps, ants, midges and beetles are generally accountable for pollinating a huge majority of the world's flowering plants.

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14. Buzz pollination involves grasping a flower in jaws and vibrating the wing muscles to dislodge the collected pollen grain.
15. Entomophagy describes a feeding behaviour that includes eating insects. Besides, non-human creatures, the term can also refer to the practice of eating insects among humans.
16. Edible insects are being promoted as a food source for three primary reasons namely: environmental benefits, nutritional value and livelihood opportunities. Edible insects have a high feed conversion efficiency (the quantity of feed required to increase the weight of a livestock by a kg) as they are cold-blooded.
17. Edible insects (insects that are fit for human consumption) are raised as livestock in specialized insect farms, is known as insect farming.
18. The World Edible Insect Day is celebrated on 23 October.
19. Factors which affect the population and development of insects can be grouped into four categories namely:
    (1) Physical factors
    (2) Nutritional factors
    (3) Host associated factors
    (4) Biotic factors
20. Antibiosis refers to adverse effect of the host plant on biology i.e., growth, survival, development or reproduction of insects as well as of their progeny.
21. Termites are a group of insects for which atmospheric humidity is an important ecological factor. Termites prefers a relative high humidity of 90-95%.

4.9 SUMMARY

- Hoshomin, the Queen of China, introduced sericulture for the first time in China.
- Voltinism indicates the number of broods or generations of an organism in a year under natural environmental conditions.
- Moulting or molting, also known as shedding, or ecdysis, refers to the phenomenon of casting outer layer of skin at specific points in the life cycle of organism.
- The top producers of silk in the world are India and China.
- Oak tasar silkworms feed on oak trees and were introduced from foreign countries.
- The overall life cycle of the silkworm is approximately 6-8 weeks.
- Muga silk is found only in in the Brahmaputra Valley of India.
- Drying or stifling refers to the killing of pupa present inside the cocoon so as to make them suitable for storage.
- Reeling refers to the extraction of continuous silk thread of a desired thickness from the cocoon without any nick/break.

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- Charka reeling is a manually operated system where inferior quality or defective cocoons are reeled.
- Silk is a highly lustrous fibre among all the natural fibres.
- Majority of the commercial silk produced worldwide is referred to as mulberry silk.
- The tasar silkworms are wild silkworms and belong to the genus *Antheraea*.
- Honeybees are native to the Eurasian as well as African continents and were introduced to the Americas and Australia by European settlers.
- The scientific name of honey bees is 'Apis', which is derived from Latin word for 'Bees'.
- Honey bees are the primary reason for the process of pollination.
- Honey making by bees is a specialized procedure in which the bees collect nectar from flowers.
- Worker bee secrete chemical secretions or pheromones from Nasanov gland which are located inside the tip of abdomen.
- Lac Insect belongs to Laccifer of superfamily Coccoidea of order Hemiptera.
- The twigs with thick encrustations are cut and removed from the site. This is called stick lac.
- The first step in the processing of lac involves removal of lac encrustations from the twigs of host plants by scraping.
- Pollination refers to the transfer of pollen from a male part of a plant to a female part of a plant, later enabling fertilisation and the production of seeds, by a pollinating agent.
- Honey bees are the most important pollinator of many garden plants as well as commercial fruit trees.
- Entomophagy describes a feeding behaviour that includes eating insects.
- Edible insects (insects that are fit for human consumption) are raised as livestock in specialized insect farms.
- Insects are poikilothermic; hence they do not have any mechanism to regulate the body temperature.
- Moisture/relative humidity is required for metabolic reactions and transportation of salts in insects.

4.10 KEY TERMS

- **Sericulture:** Sericulture refers to the process of cultivating or growing silkworms.
- **Voltinism**: Voltinism indicates the number of broods or generations of an organism in a year under natural environmental conditions.
- **Moulting**: Moulting or molting, also known as shedding, or ecdysis, refers to the phenomenon of casting outer layer of skin at specific points in the life cycle of organism.

NOTES

- **Charka reeling:** Charka reeling is a manually operated system where inferior quality or defective cocoons are reeled.
- **Royal jelly:** Royal jelly is a secretion released from the hypopharyngeal glands of nurse-bees.
- **Propolis:** Propolis is the resin-like exudate which is collected by honey bees from the trees.
- **Pollination:** Pollination refers to the transfer of pollen from a male part of a plant to a female part of a plant, later enabling fertilization and the production of seeds, by a pollinating agent.
- **Entomophily:** Entomophily refers to the form of pollination whereby pollen is distributed by insects.
- **Entomophagy**: Entomophagy describes a feeding behaviour that includes eating insects.

4.11 SELF-ASSESSMENT QUESTIONS AND EXERCISES

Short-Answer Questions

1. Write the classification of insects based on moultinism.
2. Name five major species of silk worms reared in India.
3. Which are non-mulberry silk worms?
4. Which are the products of culturing honey bee?
5. Name the host plants of Laccifer lacca.
6. Write the steps of lac cultivation.
7. What are the application of lac?
8. Write a few adaptations of the plants that are pollinated by insects.
9. Which Topographic factors are responsible for affecting the population of insects?
10. What is the predator prey relationship?

Long-Answer Question

1. Describe the life cycle of mulberry silkworm in detail.
2. Explain the process of the production of silk.
3. Describe life cycle of honeybee.
4. Elaborate on the life cycle of lac insect.
5. Discuss insect pollinators in detail.
6. Describe insect farming.
7. Briefly describe the ecological factors affecting the population and development of insects.

4.12 FURTHER READING

NOTES

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