Part 3

Applied Entomology

Section Seven

Productive Insects and Usefulness of Insects

◆ Chapter 68

Apiculture

Applied Entomology generally connotes the study of insects injurious to man, livestock and crops, which have been dealt with under Part II. However, there are a number of insects, which are beneficial to man. A few important species of insects produce certain substances during the course of their life, which are appropriated by man for his own use. Beekeeping (apiculture) has been practised by man from very early times to gather honey and beeswax. Sericulture is a branch of technology, which is primarily insect-based, the various silkworms yielding silk fibres of commercial value. Sericulture involves rearing of silk worms, which are domesticated either completely or partly depending on the species, from which silk is extracted. Lac industry of India is exclusively the exploitation of the lac insect. Entomologists have neglected the study of the roles played by insects as pollinators. With the advent of biological control measures, insects have been used to fight insect menace. Though the damages done by insects outweigh the benefits of insects to mankind, it should be borne in mind that human ingenuity has exploited the services of these insects to a considerable extent.

Honey bees, silk worms and lac insects constitute the most important productive insects which are briefly mentioned here.

HONEY BEES provide man with nutrient rich honey and beeswax, besides playing an essential role in the pollination of crops many of which depend solely on them. The exploitation of bees as natural resources did not attract sufficient attention till the beginning of the 20th century, though a few attempts had been made to domesticate the different species of honey bees by the end of the 19th century. India has a wealth of bee species, some of which produce efficient crops of honey.

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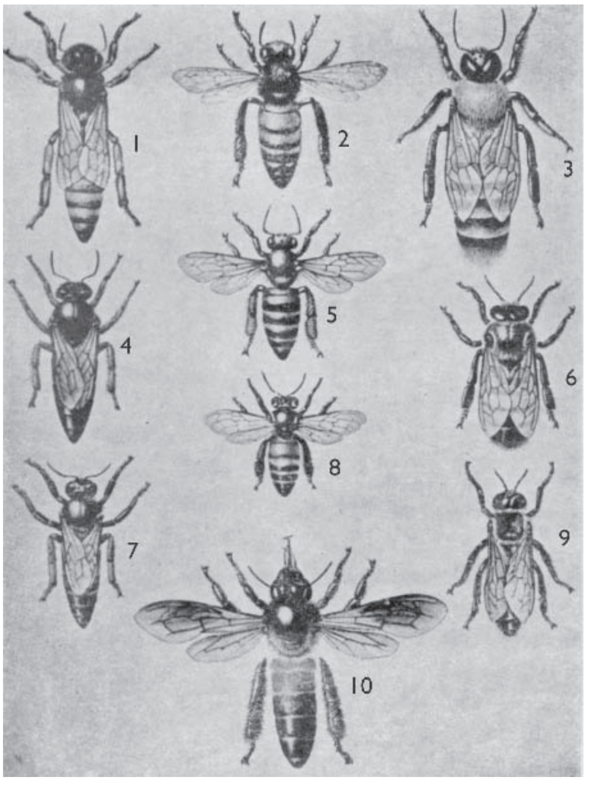
The five principal species of honey producing bees are *Apis cerana indica*, the Indian bee, *Apis dorsata*, the rock bee, *Apis florea*, the little bee, *Apis mellifera*, the Italian bee, (Fig. 68.1) and *Trigona iridipennis*, the dammar bee.



▲ **Fig. 68.1** *Indian Honey bees: 1-3 Apis mellifera Queen, Worker and Drone; 4-6 Apis cerana indica Queen, Worker and Drone; 7-9 Apis florea Queen, Worker and Drone; 10 Apis dorsata Worker (after C. C. Ghosh-from Textbook of Agricultural Entomology, H.S. Pruthi, 1969.)*

Apis dorsata is the biggest known honeybee in the world, usually confined to the forest-clad hills and in evergreen forest areas of the plains. The single comb it constructs is a very large one, 1.0 to 1.5 metre long, 0.5 to 1.0 metre wide and overhangs precipitous rocks or on inaccessible branches of trees. Temperamentally they are unfit for domestication even though they produce large amounts of honey ranging from 18 to 36 litres of honey depending upon the size of the colony. In the deep forests of South Andaman, crushed/

squeezed stems of *Amomum aculeatum* (Zingiberaceae) or sap of its flowers, or whole plant sap and leaf juice of *Zingiber squarresum* (Zingiberaceae) when rubbed on the body of the honey collector act as tranquilizer for the giant honey bee *A. dorsata*.

Apis cerana indica is a smaller-sized honey bee, which is domesticated in view of its mild temperament and non-migratory habit. It constructs several parallel combs inside cavities, generally in hollow trees. Its flight range is 600-1040 m.

Apis florea is a smaller-sized honeybee and constructs tiny single combs on twigs, crevices in buildings, bushes, etc. This species is unfit for domestication in view of its poor honey gathering capacity and migratory habit.

Apis mellifera is an introduced species and has been domesticated. It is performing better than the Indian bee and is replacing it in domestication in many parts of the country. Its flight range is 3-14 km.

Trigona iridipennis is a very small dark bee, which nests in crevices in walls, hollow trees, etc. Though they possess vestigial stings, they are known as "mosquito" or "stingless bees." They secrete wax, which is mixed with earth or resin and the resulting dark material is called "cerumen." The wax is secreted between the abdominal tergites of the workers. The cells, made of cerumen, are clustered irregularly. The group of cells is enclosed in batumen (a protective layer of plant resin or propolis and beeswax). The nest has 4-50 cm long, funnel-shaped waxen entrance tube edged with a sticky substance. The entrance is guarded during the day by workers and closed at night as protection against ants and other predators. Foragers communicate the location of food source to other workers by laying a scent trail and also by leading them to food. Honey and pollen are stored separately in dark-coloured globular cells and their tiny ellipsoid pellet-like brood cells are constructed individually. The honey produced by this species is only in very small quantities. In Coimbatore its reproduction occurred mostly during March to June. New colonies are started by swarms containing many workers and a queen.

History: The pot hive method of bee keeping utilising hollowed out trunks of trees or empty pots smeared with wax and sweet scented leaves of *Cinnamomum iners* inside, and kept in forests to attract bees, was practiced for quite some time in Mysore, Coorg, Kashmir, Malabar, etc. It was in 1907 that the scientific method of bee keeping commenced. Initially the apiaries were developed with hives bearing movable frames and with every passing year the number of apiaries increased. The period from 1875 to 1914 was the golden age of bee keeping since it was during this period that the industry was established on a solid foundation. Since then several modifications of hives have emerged such as the book hive, Madhusagar hive, house hive, nuclear hive, single walled Dadant hive, British standard hive, Langstroth hive, Jeolikote hive and Newton hive. Of these, the Newton hive is the most popular.

Apiculture has proved to be an important cottage industry. Apiaries are usually located at places where there is abundance of pollen and nectar-yielding plants within a radius of one kilometre. A young orchard with sufficient shade, less windy and with fresh running water appears ideally suited for the location of apiaries and may contain 50 – 100 colonies, placed two to three metres apart in rows.

The Indian honeybee *Apis cerana indica* and the Italian bee *Apis mellifera* are hived and reared in specially designed hives for its honey. A colony consists of the queen, the workers (sterile females) and the drones (males). In South India the period from November to May constitutes the breeding and honey flow season and the period from June to October is the slack season. The bees are usually most active in the collection of nectar and pollen at a temperature range of 25° to 27° C and relative humidity of 70 to 80%. Further, the honey yield is directly proportional to the availability of bee pasturage in a locality. The bee is capable of carrying pollen loads of 26 to 35 % of its body weight.

The females develop from fertilised eggs and the males as parthenotes. The queen after the nuptial flight stays in the old hive or in a new one and commences egg laying. It lays about 500 eggs per day singly in the hexagonal cells of the comb. The cells in the comb in the brood chamber in the lower part of the hive are reinforced with propolis and these constitute the brood cells. The cells in the combs in the super of the hive are made up of pure wax and honey is stored in these cells. The longevity of the queen is three years.

The grubs that hatch out from fertilised eggs are fed for a day with "royal jelly" and on bee-bread during the rest their life cycle as grubs. The royal jelly is a nutritious food rich in protein, 40–43 % by weight. It comprises of 15–18% proteins, 2–6.1% lipids, 9–18 % carbohydrates and 0.7–1.2% ash. The adults that develop from these give rise to workers. The development from egg to adult takes about 26 days and the worker bee lives for 45 to 80 days. These attend to indoor activities of the hive, such as cleaning the hive, nursing, building combs, etc. extending up to the first 13 days of their life, and thereafter devote to foraging activities. The grubs that hatch out from unfertilised eggs are fed with royal jelly for the first three days and with a mixture of royal jelly and bee-bread until they pupate. These develop into males. The development period is about 23 days and it lives for about 60 days. They develop in large numbers only in certain seasons. The cells in which the workers develop are smaller, numbering about six per sq. cm. In certain seasons a few special cells of larger size are constructed at the lower part of the hive and the grubs that hatch out from the fertilised eggs laid in these cells are fed with royal jelly throughout and they develop into queens.

By the beginning of the honey season when the population of a colony has sufficiently increased, swarming takes place in which the ruling queen and a part of the population of bees move away. The group thus emigrated in a mass is collectively known as a "swarm".

Swarming in bees helps in the dispersal of the species. A preponderance of drones in the brood is the first symptom. After a fairly large number of drones have emerged and many more are under rearing, a number of queen cells are constructed along the lower border of the brood combs and a fertilised egg is laid in each. By the time the inmates attain the pupal stage the reigning queen and a large proportion of workers swarm out and establish elsewhere. This is the "prime swarm". Now the new queens emerge. If the population is sufficiently strong at the stage when a new queen emerges, she goes out and this process goes on, until the strength of the parent colony is reduced to the minimum. If a number of queens emerge at a time and swarm out only one survives. When the colony becomes too weak to send out any further swarms the emerging queen kills all her rivals by biting and destroying other queen cells in the hive. To ensure a regular crop of honey, a bee colony should possess a significant number of individuals as workers and the yield of honey is directly proportional to the hive populations. In a thriving colony the bee population is estimated to be 26,300 to 35,700 and this strength is needed for storing up surplus honey. Local weather conditions play a vital role in influencing fluctuations of the bee number and hence in the amount of honey yield. Barring slight variations, there appears to be two main seasons: a slack season between June and October and a honey flow season from November to May.

It is also known that bees show certain amount of discrimination in visiting plant species for gathering honey. Available information on the bee pasturage plants indicates that among the pollen yielders, maize (*Zea mays*), and jowar (*Sorghum vulgare*), are the best, followed by pearl millet (*Pennisetum typhoideum*), castor (*Ricinus communis*), coconut (*Cocos nucifera*) and *Peltaphorum ferrugineum*. Of the nectar-bearing plants, cotton (*Gossypium* sp.), *Gliricidia maculata*, tamarind (*Tamarindus indicus*), neem (*Azadirachta indica*) and banana (*Musa paradisiaca*) are outstanding. The quantity of pollen collected by a bee per trip is on an average 0.025 g. The Indian bee is said to be capable of carrying pollen loads of 26.35 % of its body weight and compares very favourably with the European bees. The maximum quantity of nectar collected by a bee per trip is about 0.00323 g. During the lean periods, in order to sustain honey production in apiaries and to stimulate brood rearing and increase in the population, artificial feeding on dilute honey and sugar syrup is resorted to in the case of bees like *A. mellifera*.

The taste and colour of honey varies according to the source of the plants from which nectar is collected. It is light coloured with mild flavour from soapnut trees; yellow from mustard; dark amber coloured with strong flavour from *Dalbergia*; strong unpleasant odour from *Polygonum*. Honey in the prosperous season is extracted once in ten days, the annual yield varying with localities.

The role of bees in pollination is well known. Setting of fruits and seeds and increase in crop yields need no citation to highlight the parts played by the bees. The importance of bees in pollination in cotton and sunflower needs no mention.

A few natural enemies present serious problems in apiculture. They are the greater wax-moth *Galleria mellonella* and the lesser wax-moths (*Achroia grissella* and *A. innotata lankella*. The other bee enemies include the wasps *Palarus orietnalis, Vespa cincta* and *V. tropica* var. *haematoides*, the reduviid bug *Acanthaspis siva*, the tenebrionid beetle *Platybolium alvearium*, the black ant *Camponotus compressus*, the death's head moth *Acherontia styx,* the leaf cutter bee *Megachile disjuncta*, cockroaches, the arachnid *Ellingsenius indicus*, lizards and the birds *Dicrurus ater* (drongo) and *Merops viridis* (bee-eater).

The ectoparasitic mite *Tropilaelaps clareae* occurs throughout the year in colonies of *A. mellifera,* being serious during March-April and October-November in the Punjab. Dusting with sulphur on the top of bars inside the beehives at 1 g/frame gives significant mortality of the mite and application would be needed at fortnightly interval. The ectoparasitic mite, *Varroa jacobsonsi,* infects *A. mellifera* in Delhi, Punjab, U.P., Karnataka and Kerala. The endoparasitic tracheal mite, *Acarapis woodi,* is prevalent on both the species of honey bees in Kashmir, H.P., Uttar Pradesh and Punjab.

The honey bee diseases caused by an iridescent virus and the Thai sacbrood disease by a virus, the American foulbrood by *Bacillus larvae* are important.

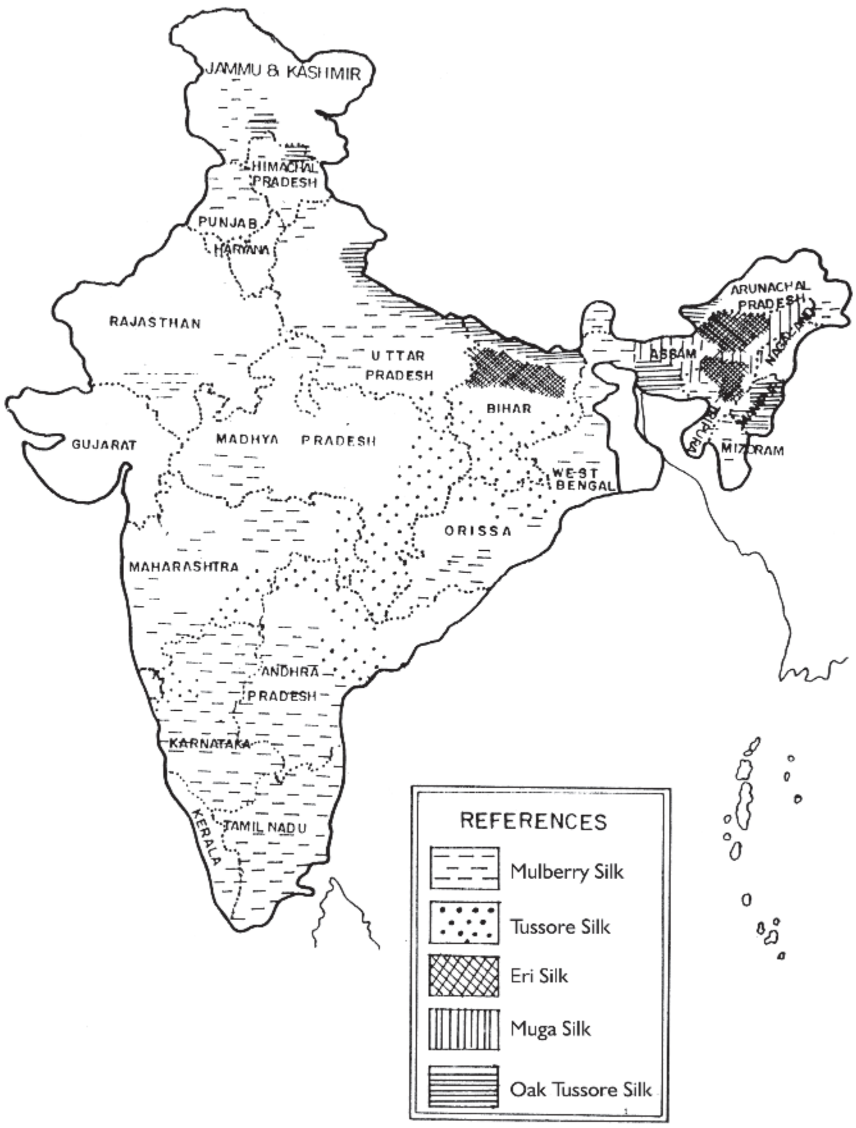
◆ Chapter 69

Sericulture

Since time immemorial, silk has become an inseparable part of Indian art and culture, and is a labour-intensive and agro-based industry. Sericulture plays a vital role in the rural economy of this country. Although it was China, which had the credit of discovering silk, it was kept secret for centuries. India now occupies a unique position in the world for being the only country with its rich sericigenous fauna to produce pure mulberry silk as well as all the three varieties of non-mulberry silks, i.e., Tasar, Eri and Muga silk. Of the latter varieties, India holds the world monopoly so far as Muga silk is concerned and it is particularly produced in various areas in and around Assam.

Pure silk is produced by *Bombyx mori* on mulberry leaves, while the other varieties of silk are produced by *Antheraea mylitta, A. assamensis* and *Samia cynthia*, yielding Tasar, Muga and Eri silks respectively. Besides these the hybrid strain produced as a result of cross-breeding of a Chinese species *Antheraea pernyi* with *A. proylei*, produces Oak Tasar silk.

From the point of view of silk-yielding potential as early as 1909 Lefroy recorded as many as 26 species of Lepidoptera producing silk. Of these some of the more important and well known species are the Indian moon moths *Actias selene, Sonthonnaxia maenas, Proctias sinensis*; the great Indian atlas moth *Attacus atlas* producing “Fagara silk” and *Archaeoattacus edwardsi*. The wild tasar moths include *Antheraea affrithi, A. helferi, A. knyvetti, Cricula trifenestrata, Leopa katinka* and *Rhodinia newara*. These species do not appear to be viable for exploitation. The biology of the principal silk producing species, the mulberry silkworm, exploited for commercial purpose, is briefly mentioned here. The silk producing regions of India are depicted in Fig. 69.1.

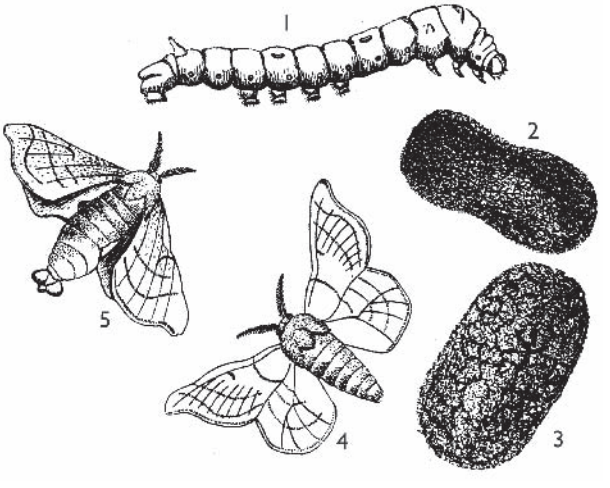


▲ **Fig. 69.1** *Map of India showing silk producing regions (Courtesy: Annapurna Dhal, 2000)*

1. The Mulberry Silkworm *Bombyx mori*

Silk is produced by the completely domesticated bombycid species, *Bombyx mori* (Fig. 69.2). It feeds only on mulberry leaves. It is distributed mainly in the areas of Assam, Bengal Bihar, Orissa, Madhya Pradesh, Maharashtra, Karnataka and Jammu and Kashmir.

Being domesticated, *Bombyx mori* can conveniently be reared under controlled conditions up to their cocoon formation, which is not allowed outdoors for various reasons. The species is either uni-, bi-, or multivoltine and depends on the number of generations per year. Univoltine races occur in Europe, Kashmir and the Punjab, multivoltines occurring in South India, Assam and Bengal. But from the quality point of view, the uni- as well as bivoltine forms appear much better than the multivoltines. Silk is produced by the labial glands that are enlarged anteriorly into a reservoir, which is produced into a duct, the two ducts on each side converging into a spinneret. The viscous secretion of the glands, on contact with air, hardens to form a fine thread, the silk. Silk consists of 75 % fibroin, a tough elastic protein and 25 % gelatinous protein, siricin. Fibroin is the inner layer, and siricin, the outer. A single caterpillar produces 650 – 1300 meters of silk thread. Mulberry trees flourish well for 10 – 12 years and every year six to eight crops of leaves are harvested, yielding 25 – 30 metric tonnes of green leaves. About 50 – 62 % of the silk in the cocoon is reelable and forms the raw silk, the rest being waste silk. Estimates indicate that 60,000 cocoons yield a kilogram of raw silk, requiring about a ton of mulberry leaves.



▲ **Fig. 69.2** *The Mulberry silkworm stages: 1. Larva, 2 & 3. Cocoons, 4 & 5. Moths (from Indian Museum Notes)*

Adult moths are creamy in colour, about 2.5 cm long, living for two or three days after emergence from cocoons. Mating occurs soon after emergence, each female laying 300 – 400 brownish white, seed-like eggs in masses. Eggs hatch in 8– 12 days, the caterpillars feeding on mulberry leaves and moulting four times. The full-grown caterpillar is about 5 cm long, the larval period extending from 28–30 days. Prior to pupation, a long, continuous strand of silk is spun to form an oval cocoon, prepupation taking place within the cocoon and the adult emerging in 10 – 12 days. It takes about six to eight weeks to complete the life cycle. The adults are incapable of active flight.

Silkworm Races The Central Silk Board (CSB) has brought out a system of 'authorisation of silkworm races'. Test rearings are done twice a year at 14 centres in the country and silkworm hybrids authorised by CSB are exploited commercially in sericulture. Mulberry silkworm hybrids for different states such as Andhra Pradesh, Assam, Bihar, Madhya Pradesh, Orissa, West Bengal, Jammu & Kashmir and Uttar Pradesh have been identified. In India, over 95% of commercial silk being produced is from multivoltine female × bivoltine male parent (cross breed). The hybrid BL23 x NB4D2 is meant for rainfed areas in Karnataka and BL24 × NB4D2 is for irrigated areas in all seasons. Rearing package for the above has been developed by the Central Sericultural Research & Training Institute, Mysore (CSR & TI).

The CSR & TI, Mysore initiated breeding work for production of quality silk utilising two Japanese commercial hybrids, which resulted in the evolution of highly productive CSR breeds. The CSR races authorised by CSB for commercial exploitation include CSR 2, 3, 4, 5, 6,12, 16, 17, 18 and 19. Similarly with emphasis on robustness KSSRDI, Bangalore evolved two races viz., KSO1 and SP2, which were bred utilising South Koran, Taiwanese bivoltine, NB4D2 and Pure Mysore races adopting hybridisation and selection method. The hybrids KSO1 × SP2 and SP2 × KSO1 proved to be better hybrids in respect of hybrid vigour, robustness and productivity.

Sericulture Successful sericulture depends on quality silkworm eggs. It is important that the grainage room and implements are disinfected and kept ready to receive seed cocoons. The seed cocoons, free from disease, are to be packed loosely, either in perforated plastic crates or bamboo baskets, and transported to respective destinations during cooler hours of the day. Immediately after receipt, the seed cocoons are to be spread on trays in a single layer and unhealthy or spoilt cocoons, if any, should be removed and discarded. The healthy cocoons are preserved in a room at 25 ± 1°C temperature, 75 ± 5% R. H., and 12 hours light and 12 hours dark conditions. Complete darkness is to be maintained on the previous day of emergence, to avoid irregular emergence of moths.

After 1-2 hours of emergence, the male and female moths are allowed to pair for 3.5 to 4 hours of pairing and then depaired by moving side ways without injuring the reproductive organs. The mated females are then taken in a separate container and induced for urination. They are placed on egg sheet and covered with cellules and kept in dark condition for oviposition.

Washing of eggs in formalin solution helps in firm adherence of eggs to the sheet and sterilises the eggs. The eggs are subjected to ideal condition of incubation viz., 75 ± 5% R. H., 25 ± 1°C temperature, 16 hours light and 8 hours darkness. Loose egg preparation method is also being practiced and loose eggs are preferred due to uniform egg number, increased egg recovery and easy and better management. Starched sheets are prepared and spread in the oviposition tray and female moths at 40-50 (bivoltine) or 50-60 (multivoltine) per sq. ft. are allowed for oviposition. The sheets are soaked in water for 20-30 minutes and the eggs are gently dislodged and collected into nylon mesh bags. They are dried by switching on the fan. In the case of bivoltine eggs acid treatment is done, washed, then dried and packed. In South India, multivoltine, pure multi-bivoltine, bivoltine pure and bivoltine hybrid silkworm eggs are used for silkworm rearing.

The development of multivoltine and multi-bivoltine embryo is a continuous process and after oviposition, the eggs hatch out within 10 days. If hatching is required to be postponed it can be done by refrigeration/cold storing methods.

Silkworm Rearing Silkworm eggs are to be handled with care during transportation. It is ideal to transport eggs on the second or the third day of oviposition during the cooler hours, packed in a bag made of rigid plastic mesh lined inside with thin foam. This is again placed in a card board box with thermacol lining and a wet foam pad to maintain humidity and aeration. Appliances/devices/methods such as BOD incubators, spreading of eggs on a clean and disinfected wax paper surrounded by wet foam pads, earthen pots or double walled chambers have been developed and recommended for egg incubation. The core activity of sericulture industry is production of quality cocoons in appreciable quantity. Factors which influence these are leaf yield (12–15 kg required for rearing a hybrid), selection of races/combinations, rearing house with an ante room to prevent Uzi fly, a separate chawki rearing building, etc.

Transfer of the newly hatched larvae from eggs on to the wax paper or rearing bed is known as “brushing”. In a 4' × 3' tray, 50 dfls (disease free layings) can be brushed and reared up to first moult and 25 dfls up to second moult. The egg sheets are distributed in required number per tray before hatching. Fresh, tender and succulent mulberry leaves (with 80–85% moisture) from a well maintained garden are collected and chopped to 0.5 – 1.0 cm^2 and spread over the hatched larvae on to the egg cards. After 30 minutes, when all the worms have crawled on to the leaf, the leaves along with the worms are transferred on to the wax paper on a rearing tray with the help of a soft feather and arranged in the form of a thin bed. Clean wet foam pads are kept around the rearing bed and covered with a paraffin paper to maintain the humidity. The trays are piled one above the other in the form of a box to conserve leaf moisture for a longer period.

In the case of loose eggs two layers of cotton/nylon net is spread over them. On hatching, chopped leaves are spread over the net. After an hour, the worms along with the top net are lifted and brushed in a chawki tray.

Rearing of young age silkworm up to second moult is called "chawki rearing", which usually lasts up to 10 days. Under optimum rearing conditions, the worms take 3 to 3½ days to settle for first and third moult, and 2 to 2½ days for second moult. At the end of fifth stage i.e. on sixth or seventh day, larvae reduce leaf consumption, release wet faecal matter, shrink in size, body becomes translucent and start crawling with raised head on the bed. Such larvae are collected and mounted on bamboo or other types of mountages. Temperature of 24°C, humidity of 60–65% and good aeration are ideal for spinning. The cocoons are harvested on the fifth day or sixth day after spinning. Double cocoons and flimsy cocoons are discarded and cleaned cocoons are marketed.

Stifling of Cocoons Partial drying of cocoon with 75 to 80 % drying is suggested instead of steam stifling. Open pan cooking method has been developed by CSR & TI.

Silk Reeling It aims at extraction of silk filament from cocoons. Silk is produced mainly by using three reeling technologies viz. charka, cottage basin/domestic basin and multi-end technology. Re-reeling is done to transfer the raw silk reeled on small reels to a large reel (1.5 m circumference) to set uniform width, weight and length of the skein. It is followed by silk finishing: lacing and silk skeining, book making (2 kg books) and long skeining and long book making (5 kg books). Each book is packed with paper and polythene to protect raw silk from damages by moisture and insects.

Sericultural Diseases Pebrine caused by a microsporidian, *Nosema bombycis*, is a chronic disease in silkworm, being transmitted to off spring by transovarial transmission from mother moth. Silkworm gets infected while feeding on contaminated mulberry leaves and from surface contaminated eggs. Disinfection of seed production unit, appliances, silkworm rearing house surroundings and silkworm egg surface are suggested.

Grasserie, also known as Haluthonde, is caused by nuclear polyhedrosis virus, a baculovirus. Disinfection as suggested above prevents infection. In addition, in case of high incidence of disease, spray 0.3% slaked lime solution in rearing house and appliances.

Flatcherie is a syndrome associated with infectious Flatcherie, Densonucleosis, cytoplasmic polyhedrosis, bacterial diseases, and *Thatte roga* in silkworm. It may be caused by these viruses individually as well as in association or each in association with Streptococci and Staphylococci bacteria (*Thatte roga*). Preventive measures suggested above can be followed.

Muscardine is caused by *Beauveria bassiana* and Aspergillosis by *Aspergillus flavus, A. oryzae* and *A. tameri.* Formalin 3%/bleaching powder 2% in 0.3% slaked lime solution is suggested for disinfection of rearing houses, appliances and even surroundings.

Silkworm Parasitoid The Uzi fly, *Exorista bombycis,* (Tachinidae) causes 10-20% loss to sericulture industry and occurs severely during July-November, though prevalent throughout the year. It is an endo-larval parasitoid. A female fly lays about 300 eggs at the rate of one to two eggs on each silkworm larva. The eggs hatch in two to three days and the larva enters into the body of the host and feeds on the tissues for five to eight days. It then comes out of the body of the silkworm larva and after 12–20 hours pupates in loose soil or crevice on the rearing house floor, etc. The adult fly emerges in 10–12 days. The total life cycle takes 18–24 days.

Management Infested silkworm larvae and Uzi fly larvae and puparia are collected and destroyed. Uzi infested silkworm larvae pupate one or two days earlier than the healthy ones and they should be collected and destroyed. Prevention of entry of Uzi fly is suggested by putting up nylon net to doors, windows and ventilators of the rearing house with an ante room at the entrance to the building. Uzi trap (a chemotrap) effectively traps and kills the adult flies. It is a tablet weighing 2.5 g, which is dissolved in one litre of water and kept near windows of rearing houses commencing from third instar till the spinning stage of silkworm. Uzicide, is an ovicide, available in liquid and powder forms. It is sprayed or dusted on the body of silkworms starting from second day in third instar through fourth or sixth day in five instar on alternate days except during the period of moulting. Release of an indigenous hymenopteran ecto-pupal parasitoid *Nesolynx thymus* kills the puparia of the fly.

Pests of silkworm in grainages Dermestid beetle, *Dermestes ater* DeGeer (Dermestidae) and earwig *Labia arachidis* (Yersin) (Labiidae) cause considerable loss in grainages. The dermestid grubs are controlled by dusting bleaching powder (30% chlorine) at 200 g/sq. ft. on the floor near the wall. The gunny bags/cotton bags used for storing cocoons must be dipped in 0.028% deltamethrin emulsion and shade dried. This can also be sprayed on floors and walls of cocoon storage rooms. Pierced cocoons before storage can be dusted with malathion 5% dust at 1kg dust / 10 kg cocoons. Wooden trays must be dipped in DDVP 0.076% solution, washed after 10 days, sun dried and reused. DDVP 0.076% spray can be applied on stands and storage room.

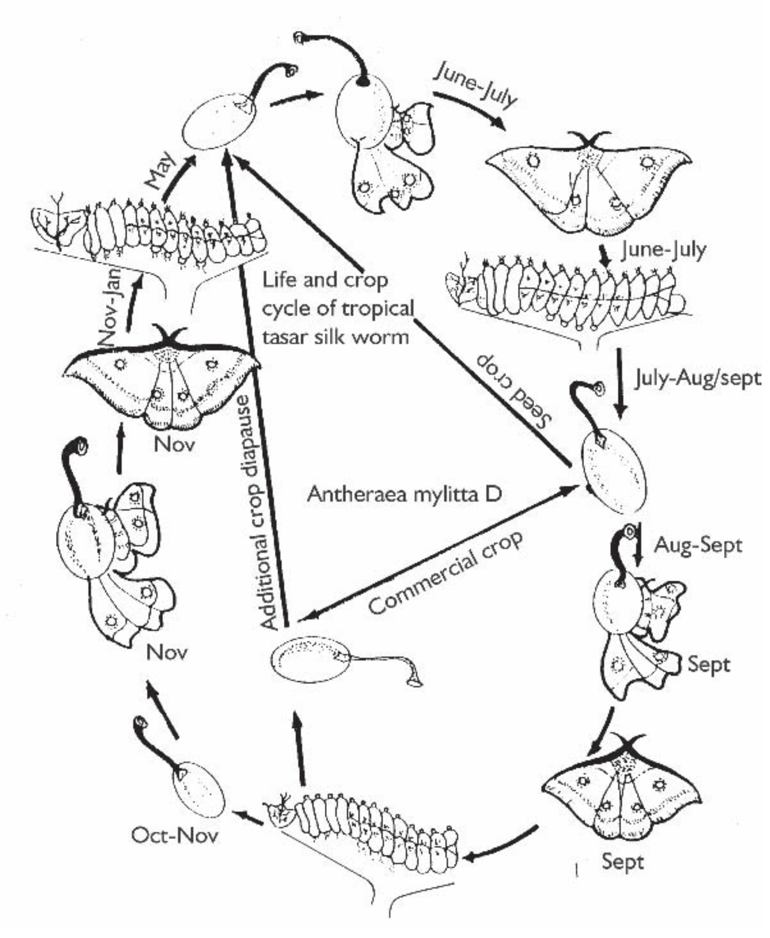
2. The Tropical Tasar Silkworm *Antheraea mylitta* Drury and The Wild Tasar Silkworm *A. paphia Linn.*

India occupies the second position in the production of tasar silk, being next only to China. At present 0.56 million hectares of forest is covered with tasar silk production while an estimated 11.6 million hectares have been identified as suitable for cultivating tasar silkworms. The tasar silk insect is found in wild and semi-domesticated condition and 25 ecoraces have been grouped depending upon their commercial characters and place of availability. The silkworms are polyphagous, generally feeding on *Shorea robusta* (Sal), *Terminalia alata* (Asan), *T. arjuna* (Arjun), *Zizyphus mauritiana* (Ber), *Lagerstroemia flosreginae* (Jarul/Patoli), *L. indica* (Saoni), *L. parviflora* (Sidha) and Hardwickia binata (Arjun), which are the primary food plants. Although colour of the silk cocoons is not affected by food, those cultivated on Sal appears to be superior to those grown on Asan or Arjun. The tasar silkworms are uni-, bi- or trivoltine and are found mainly in areas of Bihar, Orissa and Madhya Pradesh and in some parts of Maharashtra and Andhra Pradesh.

The wild tasar silkworm found in Orissa is *A. paphia* and when it occurs at high altitude (601-1000 m ASL) is known as *Modal*, the silk from cocoons having more economic traits. It is univoltine. When it occurs at low altitude (50 - 300 m ASL) is referred as *Bogei* and the cocoons produce silk of less economic traits. It may be bivoltine or trivoltine. The one occurring at mid altitude (310-600 m ASL) is known as *Nalia*, being bivoltine. Its first generation is semi-domesticated.

Antheraea mylitta is polyphagous and domesticated, feeding on leaves of Asan, Arjun and Sal. Most of the ecoraces are bivoltine and trivoltine. The ecoraces in Orissa are known as *Sukinda, Daba, Modal* and *Bogei*. Depending upon the voltinism of the race, the reproduction coincides with rain (July-August), autumn (September-October), and winter (November-December) seasons (Fig. 69.3). In Orissa *A. mylitta* is reared on Asan and Arjun plants and exhibits bi- and trivoltinism in two ecoraces such as *Daba* and *Sukinda*, respectively. *A. mylitta* grown in mid altitude is known as *Daba* and that of the low altitude is *Sukinda*.

The Oak tasar silk worm is the temperate silkworm represented by *Antheraea yamamai*, *A. proylei* and *A. pernyi* respectively, in Japan, India and China.



▲ **Fig. 69.3** *Life history of Tasar silkmoth (Voltinism) (Courtesy: Annapurna Dhal)*

Biology of Tasar Silkworms

Eggs are laid on tender leaves of the host trees and a moth lays about 200 eggs. The egg is creamy in colour, large, oval, flattened, and bilaterally symmetrical along the antero-posterior axis. The incubation period is 8–10 days. The eggs are glued firmly to one another and to the surface of deposition. The average weight of first day egg is 10.34 mg and that of sixth day egg is 9.23 mg.

The larva is greenish, elongated, cylindrical being flattened ventrally with red spiracles, robust, hairy and clothed with numerous tubercles, and the head being brown with bright ornamentations. Rarely may one come across blue, yellow and almond coloured larvae. There are five larval instars. On an average the grown up larva measures 11.30 cm long, 1.98 cm in girth and weighs 25.18 grams. The larval period takes about 35-70 days.

The grown-up larva pupates in a cocoon, which is oval shaped, closed, single shelled and light with a peduncle. The cocoons exhibit different colour types such as grey, black, yellow, greyish black, yellowish black, cream and creamy white. There are four different phases in cocoon construction, the first being nest formation, wherein the larva selects a twig and then forms a small nest or *hammock* by binding together the leaves with silk gland secretion through mouth. Then the larva comes out of the *hammock* and straps the bark 2–3 mm wide around the twig in the form of a ring. Simultaneously it initiates the peduncle formation by connecting the ring to the loop of the *hammock* with the help of few strands of silk. This process takes about 10 hours.

After *hammock*, ring and peduncle are ready, construction of cocoon proper is commenced. The larva gets itself enclosed in the cocoon made of silk and the cocoon formation takes two to three days. It then pupates inside the cocoon. The average dimension of male and female cocoon is 5.1 cm × 2.9 cm and 5.5 cm × 3.3 cm, respectively. The peduncle length in female is 5.7 cm and in male 4.0 cm. The volume of the cocoon is 28.6 cc in male and 29.5 cc in female. Normally a tasar cocoon is closed, single shelled and unipedunculate with a single pupa inside. The loop at the distal end of the peduncle helps in the cocoon being suspended firmly from the twig. Sometimes a cocoon may enclose two or three pupae and may also have more than a single peduncle. Though usually the cocoon is unishelled or monoshellate in nature, rare combination of two (bishellate), three (trishellate) and more (multishellate) cocoon shells may be noticed and are referred to as jointed cocoons. Cocoons should be harvested after six or seven days of formation. The branches are cut and the cocoons are pulled off the twig by breaking it near the ring. The pupal period ranges from 25 to 50 days.

The silk is reelable for which the pupae are to be killed before emergence of the moth, to prevent cutting of the silk thread into pieces.

The adult moth is large and beautiful. The male is brown coloured having slightly wider wing expanse than the brick-red moths. The female sepia or yellow coloured moth has widest forewing expanse whereas pink coloured moth has the shortest wing expanse. The body colour of female varies from cadmium, yellow through pinkish or brown.

Rearing

Rearing of domesticated variety is easier in comparison to wild variety. The traditional tasar rearers usually utilise thick patches of food plants of 3.0 to 3.5 m tall. It is important that same bushes are not used for two successive crops of silk in a year.

The establishment of healthier eggs of tasar silkmoths for production is very important and this is known as *grainage* (French: *Graine*-seed). The selection and preservation of seed cocoons, preparation of disease free layings and their disinfection and incubation are important aspects of grainage.

Well-formed, healthy and tough cocoons are selected after harvesting for seed purpose. The rearers purchase seed cocoons or produce their own seed. The Central Tasar Research and Training Institute, Ranchi maintains the nucleus tasar seed stock, which is supplied to its parental seed station and then to different Basic Seed Multiplication and Training Centres. These centres produce the basic seed and supply to the Pilot Project Centres of the states. This ensures supply of select good quality and disease free seeds. The seed cocoons procured should have at least 5-10 days for emergence.

If transportation of seed cocoons is involved, they are packed lossely in bamboo baskets or synthetic boxes or any perforated boxes in small quantities and transported during the cooler hours of the day or in the midnight to avoid damage due to high temperature. Cocoons are transported during diapause preferably in December-January. In the grainage room as soon as the cocoons are received they are hung in the form of garland with the help of peduncles.

The cocoons harvested out of the second crop, in case of bivoltine and trivoltine forms, enter into diapause from later part of August to later part of May, and in bivoltine and trivoltine of third crop from November to later part of May and from January to later part of May respectively. The optimum condition for preservation of seed cocoon is 25°C and 45-48 % relative humidity (RH).

Emergence of moths from the disapausing pupae commence with the onset of monsoon. The moths from the cocoons of the first crop (July) usually emerge during August-September, while those of trivoltine second crop emerge during later October, and of third crop during early November. Most of the moths emerge from the peduncle portion.

Mating takes place after three hours of emergence, the peak period being from midnight to 2 A.M. Mating may be carried out in captivity using bamboo baskets or manually and in outdoor conditions also. In outdoor mating the females are kept on the bushes during early evening hours and then the males are released. The mated pairs are collected early in the morning and kept in specially made earthen cups or card board or plastic boxes disinfected. Though egg laying lasts for seven days, the eggs laid in batches of 5-10 eggs up to three days are used for rearing. In a commercial grainage five moths are kept together for egg laying. After the third day of egg laying the moths are examined for perbrine, viral and bacterial diseases and the eggs laid by diseased moths are discarded. The eggs of healthy moths are termed Dfls (disease free layings) or certified eggs.

The eggs are disinfected with 5 % formalin solution for 5 minutes, washed with distilled water, shade dried by spreading over blotting paper, and then kept in laying boxes for incubation.

The eggs are transported within six days of oviposition in small bags of muslin cloth of size 22.5 cm × 10 cm, which may accommodate 100 Dfls and then put in perforated plastic or bamboo baskets.

The egg boxes are placed in a room for incubation and incubated at 28° – 30°C and 72-80 % RH. The hatching of eggs commences on the seventh or eighth day and gets completed in two or three days.

After the larvae hatch out from the eggs, the placing of larvae on the leaves of host plants is very vital. Traditionally leaf cups containing eggs are tied on to the bushes, or freshly emerged larvae are brushed on to the foliage of host plants. Out door rearing causes heavy mortality of first instar larvae.

Controlled rearing techniques have been developed and are being followed. The larvae are reared indoors until the first moult. The second instar larvae are allowed to crawl on to fresh twigs and then transferred outdoors. The development of economic plantation of tropical food plants of tasar has promoted the concept of early instar controlled rearing. Rearing up to third instar is done on economic plantations preferably under nylon netting. Once the larvae pass their second or third moult the twigs are cut and transferred to forest or block plantations for rearing to advanced stages. Nearly 4000 Dfls can be reared up to third instar on one hectare of economic plantations.

Diseases of Tasar Silkworms

In each season of rearing the larvae suffer from four types of diseases viz., pebrine (*microsporidiois*), polyhedral viral, bacterial and fungal diseases.

The Tasar Uzi fly *Blepharipa zebina* (Tachinidae) is parasitic on Muga and Tasar silkworms and cause loss of 30–40 % in silk yield. Other natural enemies of Tasar silkworm include *Xanthopimpla punctata* (Ichneumonidae), *Eocanthecona furcellata* (Pentatomidae). *Scanus collaris* (Reduviidae) and the mantis *Hirodulla bipapilla* (Mantidae).

3. The Muga Silkworm *Antheraea assamensis*

The Muga silk moth is restricted to the north-eastern states, particularly Assam, which holds monopoly in Muga silk production. The species is semi-domesticated and multivoltine, producing as many as five to six broods in a year. Though it feeds mainly on

Som (*Machilus bombycina*) and Soalu (*Litsaea polyantha*), the species is reported to be polyphagous feeding on as many as 18 hosts. As a result the colour of the cocoons and the quality of silk is considerably changed.

Although diapause is wanting in this species, the period of the life cycle may prolong from nearly one and a half months in summer to about three months in winter. The larvae on hatching are yellowish, but as they grow they turn to translucent green. On maturity the larvae move to the tree trunk early morning for cocoon formation, and thus can be easily collected unlike the *Antheraea mylitta.* The cocoons are light to deep brown, but white is not uncommon. Males are reddish pink, females lighter.

4. The Eri Silkworm *Samia cynthia ricini*

The Eri silk moth, also known as *Ailanthus, Endi, Errandi* silk moth, is economically important. It produces four to six crops in a year and is domesticated and mainly reared on castor (*Ricinus communis*) though it has about 29 hosts. On castor it takes about 20 days to complete the larval period. A hectare of castor yields 500,000 cocoons resulting in 250 kg of empty cocoons for silk production and 1250 kg of dead pupae. Besides the castor crop yields about 750 kg of seeds for oil extraction. The dead pupae are either consumed by local tribes, or are dried and powdered and used as feed for poultry, pigs or fish.

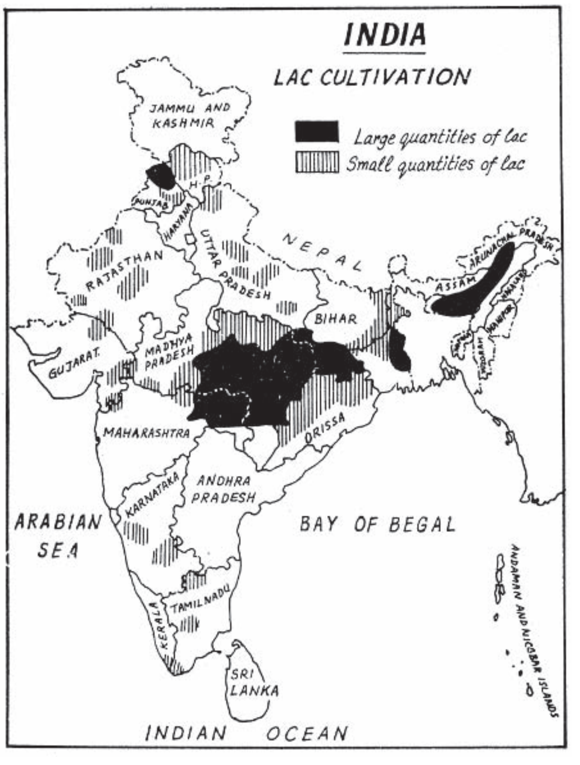
Depending on temperature the life cycle may take about one and a half to two and a half months. The eggs are oval and grey. The full grown larva is cream yellow, green or blue with prominent markings, which may be single or double dots, semi-zebra, zebra, etc. and 10 cm long. The adults are beautiful, predominantly brownish or yellowish brown. There are several sub species but *ricini* is a domesticated race since it is not easily separable from *cynthia.* The species is widely distributed, particularly in Assam, West Bengal, Bihar and Orissa, where it is exploited for the commercial production of silk. It is also known to occur in Himachal Pradesh and Uttar Pradesh.

Twenty eight grams of eggs will give about 1600 larvae which can yield 4 kg of silk after consuming leaves from about 0.5 hectare of castor crop.

◆ Chapter 70

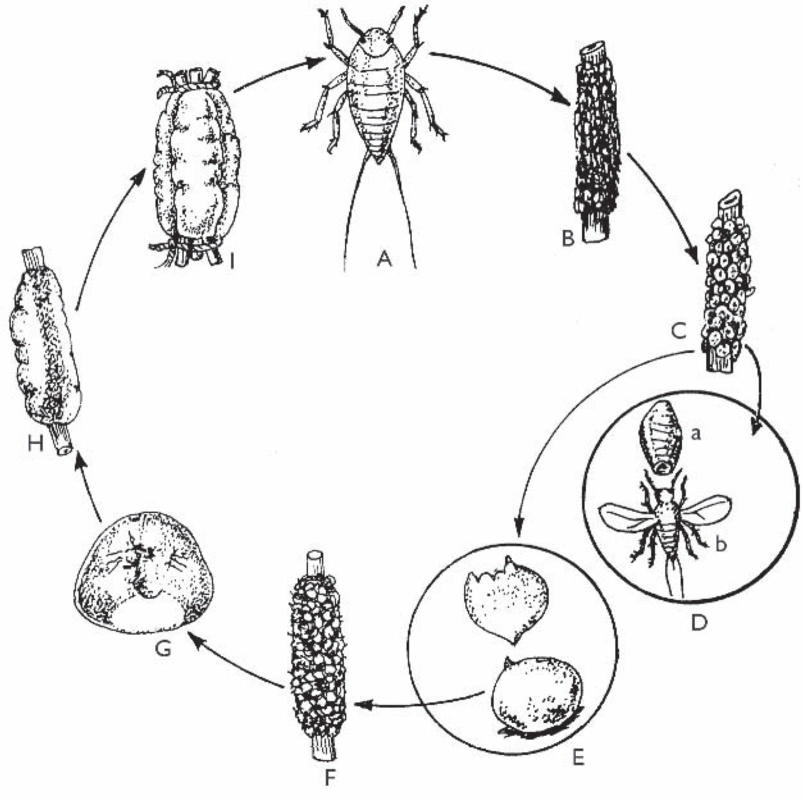
Lac Cultivation

Lac is the resinous secretion of animal origin produced by the tiny homopteran coccid *Kerria lacca*, which spends its entire life period attached to the twigs of several naturally occurring plants. The importance of lac in modern economy is considerable and has entered into the agricultural, commercial, artistic and domestic enterprises in a progressive way. Lac insects have been introduced on a wide variety of host plants and though more than 53 genera and 113 species have been recorded, only seven genera involving 14 species are considered major hosts. These include *Acacia arabica, A. catechu, Butea monosperma, Cajanus cajan, Ficus benghalensis, F. cunia, F. racemosa, F. religiosa, Leea crispa, L. robusta, Schleichera oleosa, Zizyphus mauritiana,* and *Z. xylopyra. Moghamia macrophylla, M. chappar* and *Albizzia lucida* are also known to be good lac hosts. Areas of lac cultivation in India are indicated in Fig. 70.1.



▲ **Fig. 70.1** *Lac cultivation in India.*

The lac insect starts its life history (Fig.70.2) as a tiny, soft-bodied, crimson coloured (though yellow or white forms do occur) nymph emerging in large numbers during certain parts of the year from the lac cells of the females. Each female produces 130–400 nymphs depending on the strain of the insect as well as the cropping season. The nymphs



▲ **Fig. 70.2.** *Life-cycle of the lac insect: A: Crawler B-C: gregarious settling on twigs; D: adults a- Female, b-Male E: lac cells; F-I lac encrustation.*

over the twigs and branches and settle gregariously, the settling rate being 44–103/ sq. cm. For nearly fifteen days, nymphal emergence from a female continues, but from a twig containing many lac females, emergence continues for about three weeks depending on the climate. Their glands commence secreting a day or so after settlement, the nymphs getting encased in cells of their own secretion increasing the size of the insects, which attain maturity after three months. The duration of the instars depends on the host as well as on the climate. Both male and female nymphs lose their legs, antennae and eyes after the first moult, when the sexes could be well differentiated. Males are known to live for 62 – 92 hours after emergence and a male can fertilise as many as 45 females. Winged and wingless males have slipper-like lac cells and they stop feeding after the last instar due to atrophy of the mouthparts. The female nymphs become smaller, pear or sac-like, sexually maturing after the final moult, so that the females become many times larger than the males and are the principal source of secretion. As a result of continuous secretion, lac cells increase in size and continue secretion till egg laying, when the female insect contracts forming a space within. The eggs hatch soon after laying.

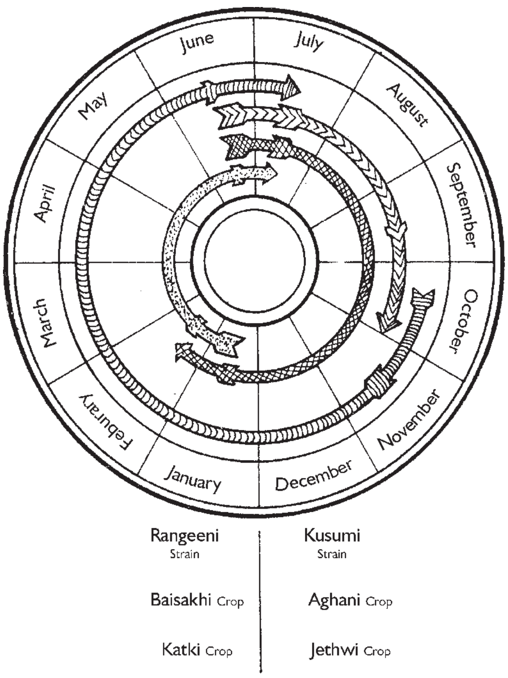
Secreting females carry the resin lac which covers the whole of the body, and as the insects crowd on the twigs, the individual cells coalesce to form a more or less single mass of encrusted lac or stick lac. This is first crushed and screened, opening the cells to wash off lac dye and remains of dead lac. After drying the lac granules and further mechanical cleaning by sieving and winnowing, seed lac is produced and after several mechanical processes shellac is produced. Stick lac has resin, sugar, proteins, soluble salts, colouring matter, wax, volatile oils, woody matter and insect bodies. Two lac strains are recognised in India – the *rangeeni* and *kusumi*, the lac crops raised from them being named after the months in which they emerge. Each strain completes its life cycle twice a year, but the season of maturity differs. In Karnataka, the *rangeeni* strain completes three life cycles in thirteen months on *Shorea talena* occurring in the forests of Karnataka, Southern Deccan and Maharashtra. In other words the lac insect brood is trivoltine, with three annual generations. All others are bivoltine. Since the lac insect entirely depends upon the host plants on which it lives and feeds, successful culture of lac depends upon the proper utilisation of the host plants.

A female may produce 300–1000 larvae so that even from a small patch of encrustation where at least a few hundred females are present, the larvae emerge in thousands and this large scale emergence is often termed the "swarming of larvae". Sticks with lac encrustation containing gravid females are called "brood lac sticks", which are tied together for the purpose of infecting other trees for the successful crop.

The overall production of *rangeeni* lac is six to eight times that of *kusumi. Kusumi* lac resin, however, is of superior quality, being mostly grown on *Schleichera oleosa, Acacia catechu, Ficus religiosa, F. racemosa,* etc., while the most common plants for *rangeeni* lac are *Butea monosperma* and *Zizyphus mauritianus.* The age of the host plants when they are mature to take lac production varies from species to species and is mostly 8–10 years. In addition to pure culture on single host plants, mixed culture when alternate hosts are used is also practised, involving *Butea* and *Zizyphus* or *Acacia* for *rangeeni* crops, and *Schleichera* with *Acacia* for *kusumi* crops. *Moghamia macrophylla* has also been found to be good lac yielder of the winter crop, while the summer crop is taken on *Albizia lucida* in alternation under mixed plantation.

Three basic ecological conditions for lac culture appear to be: a) host species deciduous for long periods during the hotter months will not be suitable; b) species should not be tried in areas liable for forest fires; and c) lac does best in open areas where there is plenty of air around the host plant and should not be tried in deep forests.

The main lac crops are *Baisakhi* (April – May), and *Kusumi* (November – December), while the subsidiary crops are *Katki* (October–November) and *Jethwi* (June–July) (Fig. 70.3).



▲ **Fig. 70.3** *Lac crop calendar.*

On an average India has produced 27,000 MT of stick lac per year, of which 53 % is in Bihar, 23 % in Madhya Pradesh, 9 % in West Bengal, and 4 % in Maharashtra. Production of lac varies from 17,000 to 52,000 MT per year, and the average yield of seed lac is about 60 % of stick lac.

◆ Chapter 71

Forensic Entomology

The utilisation of information on insects in certain criminal investigations relating to approximate period when a person is dead as revealed by observation on insects on or in corpses. Anthropologists have made sufficient observations regarding arthropods found on human remains. An interesting aspect relates to the information on blowfly biology on time of death and on whether a corpse has been removed from the place of death to another. As such Forensic Entomology is principally concerned with conclusions drawn from examination of arthropods taken from corpses and utilisation of life history informations under diverse circumstances, to estimate the time of death.

Forensic Entomology dates back to 1855 involving the knowledge of insect fauna of human corpses, such as estimates of mite eggs and life stages of insects such as act of the blow fly *Sarcophaga Carnaria.* A number of landmark publication have been made in the late 18th century, with a noble report in 1898 by M. G. Motter[1] on "A contribution study of the grave".

Forensic Entomology has not developed to the extent that it could be considered as a distinct sub-discipline. In recent years the large scale involvement in idol thefts from various localities including temples, with in many cases their being buried in the soil to escape notice, has often resulted in termite incrustations which when discovered would provide a rough idea as to how long the idols have been hidden.

[1] M. G. Motter 1898 *J. New York Entomol. Soc.* **6:** 201–231.

◆ Chapter 72

Industrial Entomology

Insects contribute economic products in such magnitude as to surpass any other group of organisms. It is no exaggeration to mention that no other life form in this planet is so inextricably bound up with that of man. Man has made use of insect products such as honey, wax, silk, dyes, medicines and even food, from time immemorial.

Honey is enjoying a renaissance along with natural foods movement and the United States is producing 100,000 MT, not to mention of other countries like China, Argentina and Australia, each of which produce over 10,000 MT. With significant amounts of diverse vitamins and equally diverse minerals, honey has been accepted as a source of essential nutrients. Another insect secretion of equal economic value is beeswax consisting of various fatty acids and hydrocarbons. It has been essentially used for waterproofing, adhesives, insulations, cosmetics and candles, with the churches using around 3 million pounds annually. History also records that they were used in ointments, industrial lubricants, paints and varnish removers, etc.

Sericulture or silk production by the silk moths is a thriving industry from ancient times, with increased inputs every year. Interestingly enough the major silk producer is *Bombyx mori,* preferably feeding on mulberry (*Morus alba)* leaves, consuming 4000 times its own weight from hatching to pupation. It is estimated that 350 cocoons are required to make a pair of silk stockings and around 1700 cocoons for a dress. China leads in world silk production with an annual in put of 30,000 MT of raw silk, which is around 80% of the world supply. Japan closely follows China with around 7,000 MT of raw silk annually. India, Korea, Brazil and Thailand are other world class producers, but comparatively low in out put.

Lac, a waxy secretion of the scale insect, *Kerria lacca,* is the only animal resin of commercial value. It is chemically a complex mixture of various polyhydroxy acids. Most of the world's lac is produced in India, which makes about 88,000 MT a year. Lac is an orange-coloured resinous secretion, which is processed to form the shell-lac of commerce. Lac is used mostly in insulators, varnish, electrical apparatus and sealants. Other uses of lac are varied from jewellery settings to mirror backings. Earlier in the 20^{th} Century it was primarily used in gramaphone record industry.

Another scale insect which produces products of industrial importance is the cochineal insect, *Dactylopius coccus,* the principal dye source, as well in cosmetics, specifically rouge and fingernail polish, besides use in medicine and fabric dyeing. The pigment is carminic acid. This acts as an ant repellent also. For commercial use, the cochineal is scraped off cactus and about 25,000 insects are required to produce around 0.45 kg of cochineal. It is the principal natural source of the scarlet-red dye Carmine, used for staining in laboratories, for dyeing silk and woolen fabrics and colouring confectionary items.

Cantharidin, a well known product of commerce, is produced in nature by the blister beetles or cantharidin beetles. Cantharidin is contained in the acrid oil excreted through the openings at the apex of the legs. The insects yielding this product in India are *Epicauta hirticornis, Lytta tenuicollis, L. actacea, Mylabris cichorii, M. pustulata, M. balteata,* etc. *Mylabris* spp. yield more cantharidin which is used in medicine and as an ingredient in hair oils. The potential of several species of *Chelidonium* for producing drugs effective in liver troubles and for other similar purposes needs to be exploited.

Plant galls which are abnormal plant growths are very rich in tannic acid, a mixture of compounds including gallic and ellagic acids. Some Oak gall nuts have 50-70% tannic acid, very much in demand for dyeing leather and used extremely by the leather industry. Tanning is a process where proteins of animal hides are complexed and tannic acid is an excellent binder of proteins and prevents rotting of hides.

Insects have been in use in medicines in several countries, and the therapeutic value of bee venom is becoming more widely recognised and there are a number of commercial preparations available today. It is particularly used in the treatment of rheumatism.

In view of diverse patterns presented by several insects like the beetles, they are used by artists, jewellers and designers for their aesthetic value. Bracelets, necklaces, neck tie pins, etc. are very often made with insect designs. Fascinating butterflies as well as large moths like the moon moth and Atlas moth (Fig. 72.1) are mounted in small glass cases as decorative items and have very good market value. Equally valuable are insect depicted paintings very significant of Japanese art.

▲ **Fig. 72.1** *Butterflies and moths in show cases for sale in Bangkok (Courtesy: B. V. David)*

Insects are being eaten in many parts of the world from ancient times to the present day. Consumption of insects in S. E. Asia is widespread with large scale business in the sale of belostomatids, the water bugs, and also its spicy juice called *namphala.* In Mexico eggs of water bugs are sold in the markets. A plate of crickets is considered as a compliment in Jamaica. Natives of Australia roast the moths of *Agrotis infusa* in oil, which taste like nuts and almonds. In Uganda long-horned grasshoppers known as "Nasenene" are eaten either raw or cooked. Further, the mounds of the large termite, *Macrotermes bellicosus,* around Lake Victoria in Uganda are regarded as the property of different families and the women and children collect them while swarming and eat them after roasting. In some African countries such as Botswana, Zaire, Zimbabwe and South Africa caterpillars of *Gonimbrasia belina,* known locally as *mopaine,* are sold which forms a good protein source in the place of beef. A similar preference has been reported among Yupka tribes of Colombia and Venezuela. In Mexico grilled queen ants and canned silkworm larvae form delicacies in restaurants. Further, the larvae of the giant skipper *Aegiale hesperiaris* is considered a delicacy under the name "Gusanos de Maguey" which are sold fresh in the market and fried before eating. In Nigeria termites, crickets, palm weevils and rhinoceros beetles are eaten. In Singapore termite queens are sold in markets, which are eaten alive, dipped in alcohol or preserved in rice wine. In Saudi Arabia locusts grilled, boiled or fried are considered delicious.

In India termites as well as grubs of honey bees are eaten by some tribes particularly in Karnataka. In Karnataka roasted termites that look like brownish popped rice are sold in the market. In Assam, Tasar and Muga silkworm pupae are eaten after stifling and reeling the silk from the cocoons. In Andhra Pradesh and Karnataka pupae of the mulberry silkworm after stifling are eaten. The dead pupae of Eri silkworm are either consumed by local tribes, or are dried and powdered and used as feed for poultry, pigs or fish.

Dungsee, a sweet product prepared from the honey dew excreted by the giant willow aphid, *Tuberolachnus salignus,* to the extent of 2–5 kg/tree depending on severity of infestation, is a rich source of carbohydrate (67.98% total sugars), protein (10.15%) and minerals (1.6%). In Spiti Valley and its adjoining areas in H.P., the tribals are known to relish this sugary substance *Dungsee.*

Other products from mulberry silk worms include the gut used in surgery, fatty matter of chrysalids for soap manufacture and the protein-rich chrysalids used as a fertilizer. The sericultural wastes such as silkworm litter, left over mulberry leaves, etc. are composted or even used for preparation of vermin compost.

Each 100 g of roasted crickets and termites appear to provide 617 calories of energy. The protein content of 100 g caterpillars is 28 g and of termites 14 g. The vitamin and micronutrient content of these insects are several folds higher. Further, insects are low in cholesterol content.

With emphasis on Integrated Pest Management the use of insects, pathogens and viruses in biological control of major pest species has assumed greater importance. A number of commercial insectaries and companies produce biocontrol agents and biopesticides and supply to the farmers.

INTRODUCTION

In thier attempts to secure food, insects inflict considerable damage to almost every part of plants and the seriousness of the attack may be decided not only by the nature of the injuries inflicted, but also by the susceptibility of the plants concerned to insect attack. The two main types of insect feeding, the biting and the sucking types, are well known and the effects of feeding may be direct, causing outright injuries or indirect through helping in the transmission of diseases—bacterial, fungal or viral.

Biting insects by feeding on the growing points of plants cause retardation of growth and often cause defoliation by feeding on leaves. They may notch the edges of leaves or make holes by feeding or roll up the leaves and feed from inside or only feed on a layer of surface tissue. Sometimes they may live concealed under loose bark of plants or cut the tender stems of plants at the time of germination. By feeding on the flower buds and flowers of plants, a reduction in seed production is often caused. In addition to feeding partially on the grains of cereal crops, they may nibble and cut off entire ear heads.

Insects with sucking habits cause a general chlorosis of leaves or a silver whitening of the leaf surface, or yellow specking or brownish necrotic lesions. Crinkling and curling of leaves is a common effect. Infestation in large numbers on the shoot and fruits often cause a premature shedding of developing fruits or piercing of the rind of fruits and sucking their juice cause premature fruit fall.

Injuries are also caused by internal feeders, feeding from within the plant tissues, some called the borers, boring the internal tissues and others called the miners, mining the leaf tissue. Many plant tissues react to insect salivary toxins during feeding, by the formation of galls or abnormal outgrowths and due to this toxaemia the growth of plants may be impaired and the setting of fruits, seed and grain adversely affected.

Another aspect of injury is through feeding by subterranean insects living in the soil, feeding on the roots of plants by chewing, or boring, sucking, or by formation of galls. In general, the attack result in stunting, discolouration, withering and death of the plants. The serious damages caused by insects to stored products are well known.

The indirect effects of feeding are evident in the loss of quality of produce through reduction in the nutritive value or marketability. Through mechanical or biological transmission of disease agents, such as bacteria, fungi and viruses, insects are indirectly responsible for the severe damage and loss caused. Injuries are also caused by oviposition.

As has been discussed under population dynamics, the equilibrium or stability of insect populations may be upset resulting in very favourable opportunities for abnormal increase of populations of species making them reach pest proportions. They reach a pest status when they are responsible for 5 % of the loss of yield and are designated minor and major pests when the loss ranges from 5 to 10 % and more respectively. According to the periodicity of their occurrence insect pests are said to be regular, occasional, seasonal, persistent or sporadic and sometimes, severe infestations often result in an epidemic. The major causes for the outbreak of insect pests is the destruction of forests or bringing them under cultivation, destruction of the natural enemies, predators and parasites, intensive cultivation of crops, introduction of new crops and new strains, accidental introduction of foreign pests, resurgence of pests, etc., to mention a few.

Prior to the adoption of control methods for insect pests, assessment of populations as well as estimation of the damage caused are important. Population assessment is usually done by actual counting as in bigger species, but mostly sampling methods are adopted. Varied sampling methods are used for different insects. These are not only according to the niches they occupy, but also on the basis of the nature of the crop attacked and distribution of the species of the pests. It may be indicated that such methods as net sweepings, sudden trappings, light, water, suction and sticky traps, are some of the common methods adopted for the control of insects.

As to the estimation of damage caused by insect pests to crops, both qualitative and quantitative methods are employed. These include conducting widespread surveys all over the country for several years or from experimental plots by comparing two plots, one subjected to natural infestation and the other maintained under controlled conditions, the degree of infestation and ultimate yield or correlation of yield per unit area in different fields with the degree of infestation of a particular pest in such areas.

The pests of crops in the field and storage, pests of forest trees and nurseries, pests of medical and veterinary importance, household pests and insect vectors of plant diseases are important categories of harmful insects. Most of them have been elaborated in detail under Part II–Taxonomy and Pestology. However, in this section the pests of importance in storage, forest, human and animal health and household are outlined briefly.

Storage Entomology

Excess moisture and mould, insects and rodents are known to be responsible for damage and loss to stored products. Excess moisture and mould are mainly responsible for the deterioration in quality of stored materials. Insects and rodents feed on the stored products and thus account for serious damage and loss. The important insect species responsible for loss in stored products are detailed hereunder.

INTERNAL FEEDERS

The larvae feed entirely within the kernels or grain or stored material.

1. THE RICE WEEVIL *Sitophilus oryzae* Linn. (Curculionidae : Coleoptera)

The weevil measuring 4 mm long is dark brown and has four light reddish or yellowish spots on elytra. The female makes a small hole on the grain, deposits an egg and covers it with a gelationus fluid. In a period of four to five months a female may lay from 300 to 400 eggs. The apodous grub feeds inside the grain, pupates there itself and emerges through an irregular hole made on the grain. The life cycle ranges from 26-28 days.

The insect infests the grain both in storage and in field. It is destructive to wheat, corn, rice, *cholam* (*Jowar*), etc.

2. THE SWEET POTATO WEEVIL *Cylas formicarius* Fb. (Apionidae)

This is a pest of importance of sweet potato in storage and in the field. See under Order Coleoptera.

3. THE LESSER GRAIN BORER OR PADDY BORER BEETLE *Rhyzopertha dominica* Fabr. (Bostrychidae : Coleoptera)

The dark brown beetle measuring about 4 mm in length has its head bent under the thorax and the posterior abdominal end blunt. Antenna is serrated and three segmented. The grubs develop within kernels or may feed in wood and paper. It is particularly a pest of unhusked paddy becoming serious occasionally. It also attacks wheat. It also infests milled products such as flour, *atta*, etc. It completes its life cycle in about 25 days.

4. THE CIGARATTE OR TOBACCO BEETLE *Lasioderma serricorne* Fb. (Anobiidae : Coleoptera)

This light brown round beetle has its thorax and head bent downward and this presents a strongly humped appearance to the insect. The elytra have minute hairs on them. Antenna is of uniform thickness. The whitish hairy grubs feed on stored tobacco, ginger, turmeric and chillies. The creamy white oval eggs are laid on the surface of stored material and the incubation period is 9–14 days. The larval and pupal periods range respectively from 17–29 days and two to eight days. Redrying of tobacco; fumigation with aluminium phosphide tablets (20–30 tablets for 28 cu. m. for 96 hrs) and aeration of tobacco for 72 hrs; storing at 16–18°C; fogging with DDVP aerosol @ 1 to 2 g a.i./28 cu. m. once or twice a week; or fumigation with magnesium phosphide 56% plate at 4 plates/25 tonnes tobacco stack and an aeration period of 48 hrs are recommended as control measures.

5. THE DRUG STORE BEETLE *Stegobium paniceum* (Linn.) (Anobiidae : Coleoptera)

This reddish brown small beetle has striated elytra and measures 3 mm long. Antenna is clubbed. It lays the eggs in batches of 10 to 40. Grub is not hairy but is pale white, fleshy with the abdomen terminating in two dark horny points. It tunnels into stored products like turmeric, ginger, coriander and dry vegetable and animal matter. The larval and pupal periods occupy respectively 10 to 20 months and 8-12 days.

6. THE PULSE BEETLE *Callosobruchus maculatus* (Bruchidae : Coleoptera)

The pulse beetle is small, dark brown and abruptly rounded at the posterior end. Adult beetle lays 80–100 white, elongate eggs singly glued to the surface of the pod in the field or on grains in storage. The grubs feed on the inner contents of pulses and pupate inside them. The egg, larval and pupal periods are respectively 5, 30–50 and 4–14 days. It causes appreciable damage to stored cowpea (Fig.73.1), grams, *Lab-lab niger*, etc. It also infests redgram pods in the field.

▲ **Fig. 73.1** *Cowpea seeds damaged by Callosobruchus maculatus*

7. THE TAMARIND BEETLE *Caryedon serratus* Oliv (Fb.) (Bruchidae : Coleoptera)

The grubs of the grey beetle attack the seeds of tamarind in storage as well as on trees.

8. THE ANGOUMOIS GRAIN MOTH *Sitotroga cerealella* Oliv. (Gelechiidae : Lepidoptera)

The yellowish white moth has pale fore wings and uniformly grey pointed hind wings with fringes of hairs. The female lays about 100 eggs on the surface of grains. The caterpillars feed on the internal contents of grains and pupate inside the grains. It may hibernate in winter in pupal stage. It inflicts severe damage to unhusked paddy. It attacks ripening grains of paddy, *cholam* and *ragi* in the standing crop and the grains in storage.

9. THE POTATO TUBER MOTH Phthorimaea operculella Zeil. (Gelechiidae : Lepidoptera)

It is a serious pest of tubers in storage and in the field. For details see under Order Lepidoptera.

10. THE CIGAR BEETLE *Demobrotis* sp.

The stored cigar-wrapper tobacco is attacked by this pest.

EXTERNAL FEEDERS

The larvae and adults feed on the grains from outside.

1. THE RED FLOUR BEETLE *Tribolium castaneum* (Herbst) (Tenebrionidae : Coleoptera)

The beetle is small, reddish brown and flat. It attacks grains, seeds, vegetable powders, dry fruits, oil cakes, nuts, museum specimens like dry insects and stuffed material, etc. The white translucent, sticky, slender and cylindrical eggs are laid at random in the produce and a female lays up to 450 eggs over a period of many months. The transition from egg to adult takes three to four weeks.

2. THE INDIAN MEAL MOTH Plodia interpunctella Hubner (Phycitinae : Lepidoptera)

This moth has brown forewings with white band. It lays about 300 eggs in clusters and the life cycle is completed in about five to six weeks. It is a pest of ear and grain of maize and ear and grain of maize and also cereals, groundnut and dried fruits. The insect contaminates grains with excrement, cast skins, webbings, dead larvae and pupae. The larva first feeds on the embryo of the grain and while feeding spins a silken web on which the larval droppings and particles of broken grain get attached.

3. THE FIG MOTH *Cadra cautella* W. (Phycitidae: Lepidoptera)

This small moth has dirty white to greyish wings with indistinct black bands. At rest the wings are sloped over the body almost like the slanting roof of warehouses. The larva mainly feeds on the germ portion leaving the rest of the kernel undamaged. It also attacks dried fruits. In bulk food grains its damage is limited to peripheral top layers only. Web formation by the insect covers the bags, floor space and mill machinery thereby leading to clogging in mills. The eggs are laid in the produce, often by simply dropping them, through the holes between fibres of jute bags, or freely on the surface of the produce. A female lays about 300 eggs. The egg, larval and pupal periods are respectively, three to six days, four to six weeks and one to two weeks.

4. THE RICE MOTH *Corcyra cephalonica* Staint. (Galleriidae: Lepidoptera)

The adult moth is greyish brown. The caterpillars web together the grains and feed within. It attacks broken grains. The grains should be cleaned and dried well in the sun.

Stored grains pest management

Preventive measures

a. Disinfest the store houses with malathion 50% EC or pirimiphos-methyl 50% EC in the ratio of 1:100 applied at 3 litres / m^2.

b. The store houses should be clean and all the swept material such as dust, dirt, rubbish, webbing, etc, should be burnt or buried deep in the soil.

c. Cracks and crevices in the wall, floor, and ceiling should be plastered.

d. Clean the grain and remove all foreign material and broken grains.

e. Excess moisture in the grain causes heating and development of mould, which give rise to disagreeable odour, discolouration and even caking, if neglected.

The bags or bins can be made damp proof by providing dunnage of bamboo poles or bamboo matting or wooden crates.

Curative measures

a. Ecological control measures: Temperature, moisture and availability of oxygen are factors needed for the development of insects. Hence, they have to be suitably manipulated through design and construction of storage structures, and storage practices so as to create ecological conditions unfavourable for the development/attack of insects. Immature stages of *Sitophilus oryzae, Rhyzopertha dominica* and *Sitotroga cerealella* get killed when exposed to temperature 80, 70 and 60°C for about 4, 6 and 11 minutes, respectively. Similarly grain stored around 10% moisture content escape from the attack of insects (except Khapra beetle). The oxygen limit inside the grain containers lethal to different insects and their stages ranged from 0.21% to 12.84%. This can be achieved by purging with nitrogen or addition of carbon dioxide.

b. Physical control measures: Use of gamma rays at doses of about 500,000 rads produce sterilisation, death within 24 hours and provides high control of microflora, while doses of about 100,000 rads produce sterilisation death in about a week and minimise damage caused by feeding.

c. Cultural control measures: Pulse beetles prefer to attack wholesome seeds and not split ones. Split pulses being dry, escape from the attack and as such are most suitable for storage than wholesome pulses. Treatment of pulses with coconut/groundnut/mustard oil at 0.25 to 0.50% can protect the pulse from the attack of pulse beetle up to 6 months.

d. Chemical control measures

(i) Fumigation of grains: The stocks of grains should be periodically examined and if insects are noticed the stock should be removed, sun-dried and cleaned. Heavily infested material should be fumigated. Fumigate the grains under cover or inside a shed with aluminium phosphide tablets (each tablet weighs 3 g) at 6 g/tonne or 1.5 g/m^3, the exposure period being six to seven days. Magnesium phosphide is also used in the form of tablets/plates. After fumigation aeration is necessary for 72 hours. Fumigation is allowed only under the supervision of trained personnel.

(ii) Surface spray of bags (prophylactic treatment): The bags should be stacked in such a way as to allow proper ventilation and sufficient moving space for periodical inspection. Malathion at 15 ml of 50% EC/4.5 litres of water may be sprayed, as a thin film on bags and about 3 litres of the spray solution may be necessary for 100 sq. m. If drenched, the humidity of grain may increase and infestation may take place. Other insecticides suggested are pirimiphos methyl 50% EC at 10 ml/litre water applied at 3 litres/100 m^2 or deltamethrin 2.5% WP at 0.5 g or cypermethrin 25% EC or fenvalerate 20%EC at 6 ml in 3 litres water/100 m^2.

The incoming new stocks of grain should not be stored along with old or infested stocks in the godown.

◆ Chapter 74

Forest Entomology

Forests constitute an area of 56 million hectares in India. Insects play a major role in the destruction of Indian forests insects due to their high reproductive potential and presence of many generations in a single year. The annual loss caused by insects to seeds, transplants, standing trees, wood and finished product has been computed to be about 10 % of the total revenue from the forests. Forest entomology constitutes study of the insect pests of forests, forest products, nurseries and seeds. It may be illustrated as below.

Forest Entomology

- Pests of nurseries
- Pests of standing trees :
    - i. Pests of natural forests
    - ii. Pests of man-made industrial plantations
- Pests of seeds and fruits
- Pests of felled and stored timber
- Pests of forest products

I. PESTS OF NURSERIES

Forest nurseries are the motherland of forestry programme; as often non-availability of large number of seedlings required for raising forests becomes a major constraint due to damage to nursery plants by insects apart from nematodes, diseases, etc. The following list indicates insects affecting forest nursery plants in India.

Insect Pest	*Host*	*Nature of Damage*
Chafers/White grubs		
Holotrichia consonguinea (Coleoptera: Scarabaeidae)	*Acacia nilotica* *Albizia lebbek* *Prosopis cineraria*	Grubs feed on rootlets and cortical tissues of seedlings
Maladera insanabilis Brenske (Coleoptera: Scarabaeidae)	*Prosopis cineraria* *Acacia nilotica*	Adults feed on leaves
Rhinyptia laeviceps Arrow (Coleoptere: Scarabaeidae)	*Prosopis cineraria* *Acacia nilotica*	Adults feed on leaves
Schizonychus ruficollis F. (Coleoptera: Scarabaeidae)	*Acacia nilotica* *Tecomella undulata*	Adults feed on leaves
Root feeders		
Odontotermes obesus (Isoptera: Termitidae)	*Acacia nilotica* *Dalbergia sissoo*	Workers feed on underground roots and stem
Microtermes mycophagus (Desneux) (Isoptera: Termitidae)	*Acacia nilotica* *Dalbergia sissoo*	Workers feed on underground roots and stem
Defoliators		
Brachytrypes portentosus Litch. (Orthoptera: Gryllidae)	*Tecomella undulata* *Albizia lebbek*	Nymphs and adults cause damage by cutting young seedlings
Papilio demoleus Linn. (Lepidoptera: Papilionidae)	*Albizia lebbek*	Larvae feed on leaves
Plecoptera reflexa Guenee (Lepidoptera: Noctuidae)	*Dalbergia sissoo*	Larvae feed on leaves
Myllocerus dalbergiae Ramamurthy (Coleoptera: Curculionidae)	*Moringa oleifera* *Dalbergia sissoo*	Adults feed on leaves
Patialus tecomella Pajani (Coleoptera: Curculionidae)	*Tecomella undulata*	Grubs feed on leaves
Myllocerus curvicornis	*Acacia nilotica, Pongamia glabra, Tamarindus indica*	Feed on leaves
Myllocerus tenuicornis & *M. viridanus* (Coleoptera: Curculionidae)	*Acacia nilotica, Tamarindus indica*	Feed on leaves
Sap suckers		
Aphis gossypii Glov. (Hemiptera: Aphididae)	*Albizia lebbek*	Sucks from tender shoots
Acaudaleyrodes rachipora (Singh) (Hemiptera: Aleyrodidae)	*Acacia nilotica* *Acacia tortilis* *Acacia senegal* *Albizia lebbek* *Cassia fistula*	Infests tender leaves

(Contd.)

Insect Pest	*Host*	*Nature of Damage*
	Dalbergia sissoo *Delonix regia* *Eucalyptus* ssp. *Leucaena leucocephala* *Moringa oleifera* *Parkinsonia aculeata* *Pongamia pinnata* *Prosopis cineraria* *P. juliflora* *Tecomella undulata*	
Helopeltis antonii (Hemiptera : Miridae)	*Azadirachta indica*	Infests tender shoots
Psylla hyalina (Hemiptera : Psyllidae)	*Albizia lebbek*	Tender shoots
Pulvinaria maxima (Hemiptera: Coccidae)	*Azadirachta indica*	Infests tender shoots
Oxyrachis tarandus Fabricius (Hemiptera: Membracidae)	*Acacia nilotica* *Albizia lebbek* *Prosopis cineraria*	Infests tender shoots
Dysdercus cingulatus Fb. (Hemiptera: Pyrrhocoridae)	*Pongamia pinnata*	Infests tender shoots
Eurybrachis tomentosa (Fb.) (Hemiptera: Eurybrachidae)	*Acacia nilotica* *Albizia lebbek* *Dalbergia sissoo* *Prosopis cineraria* *P. juliflora*	Infests tender shoots

II. PESTS OF STANDING TREES

A. Pests of natural forests

1. CHIR *(Pinus roxburghii)*

The important pests of chir are the bark borer *Cyrtorrhynchus rufescens,* and the bark beetles *Ips longifolia, Pityogenes scitus* and *Polygraphus major. C. rufescens* attacks living chir saplings. The weevil grub bores the bark and causes formation of cankerous wounds resulting in death of the tree. *Ips longifolia* (Scolytidae) bores into the bark of large tree trunks and small branches. The attack results in characteristic polygamous gallery pattern in attacked tree trunks. *P. scitus* (Scolytidae) attacks the thin green bark or rind of living branchlets and stems of young and old trees. *P. major* also attacks small branches and stems and causes polygamous gallery system.

2. DEODAR *(Cedrus deodara)*

The scolytid beetles *Ips longifolia, Pityogenes scitus* and *Polygraphus major* also attack deodar. The cicadid, *Paharia casyapae,* oviopsits in the branchlets and stems. *Ectropis deodarae* (Geometridae) defoliates the pure deodar forests of the outer ranges of the Himalayas and in Punjab. Recently about 100,000 deodar trees in Himachal Pradesh were affected by this defoliator. *Dioryctria abietella* and *Euzophera cedrella* (Pyraustidae) bore into the cones.

3. OAK *(Quercus sp.)*

The larvae of *Dorysthenes hugelli* (Cerambycidae) bore into roots of oak trees. The larvae of another cerambycid, *Aphrodisium hardwickianum,* bore into the stems of living trees.

4. SAL *(Shorea robusta)*

The sal heartwood borer, *Hoplocerambyx spinicornis* attacks felled trees, damaged trees or infected by root fungus. This is considered to be the most injurious forest insect in India. During 1997-98 it became an endemic pest of sal in M.P. and affected one sixth of the total sal forests spread in six districts covering an area of 300,000 ha inflicting a loss of Rs.2500 million. The insect attack is believed to have started in December 1995. The sal tree produces resin that attracts the insect. With the onset of the monsoon, the adult beetles emerge and mate. The female lays, on an average, 250 eggs in the bark of the tree. The incubation period is seven days. The grubs remain active for six to seven months (June to November), gnawing into the whitish sapwood and the red-brown heartwood. The grubs form galleries, eating their way in and out, and up and down the stem of the tree. It pupates within the stem and emerges when the monsoon sets in the next season. The longevity of adults is three to four weeks. The adults are strongly attracted to fresh sap of felled trees and are known to fly up to 0.8 km within five minutes and are capable of smelling the sap from a distance of 2 km. The insect was first noticed as a pest of sal in 1899 and since then several epidemics have been recorded in states like Assam, Bihar, H.P., U.P. and M.P. During 1923-28 epidemics 4,28,000 adult beetles were killed. During 1997 in M.P. about 15,100,000 adult beetles were collected and killed.

Pammene theristis (Eucosmidae) attacks the seeds, seedlings and young shoots. The lymantriid *Lymantria mathura* is a principal defoliator of Sal in Assam and North India.

5. SPRUCE *(Picea smithiana)*

The spruce budworm *Eucosma hypsidryas* Meyrick (Eucosmidae) oviposits on young buds of spruce. In each bud a single larva feeds on the undeveloped needles inside without damaging the needles that form the outer most and lowest layer. The damaged bud becomes brown and dries. This prevents normal annual formation of new shoots and results in extensive loss of radial growth. The larva of the pyralid *Dioryctria abietella* also bores the cones.

B. Pests of man-made industrial plantations

1. BAMBOO *(Bambusa spp.)*

The beetle *Estigmena chinensis* (Chrysomelidae) is a serious pest of bamboo forests in India. It attacks young clumps. *Cytrotrachelus dux* (Curiculionidae) is a borer of young sprouting culmns of bamboos. The larvae of *Cosmopteryx bambusae* mine the leaves of bamboo.

2. BABUL *(Acacia arabica)*

A dirty brown scale *Anomalococcus indicus* infests the branches and stem. The hairy caterpillars *Taragama siva, Metanastria hyrtaca* and *Euproctis lunata* also damage the leaves. The metallic coppery green buprestid beetle *Psiloptera cupreosplendens* gnaws the bark of thin shoots.

3. CASHEW *(Anacardium occidentale)*

The cashew tree borer *Plocaederus ferrugineus* (Cerambycidae) is an important pest of cashew. For more details refer to the section on Coleoptera. The leaf miner *Acrocercops syngramma* (Gracillariidae) is yet another pest of common occurrence. For more details refer to the section on order Lepidoptera.

Other insects include the shoot and blossom webber *Lomida moncusalis* Walk. and the shoot tip and inflorescence caterpillar *Chelaria haligramma* M. These are often serious pests on cashew. The thrips *Selenothrips rubrocinctus* G. and *Rhipiphorothrips cruentatus* Hood damage the leaves. The caterpillar and thrips pests are easily controlled by spray application of profenofos 0.05 %.

THE CASHEW LEAF FOLDER ***Syllepta aurantiacalis*** **Fisch. (Pyralidae)**

This species is reported from Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Orissa, Maharashtra and Goa as attacking cashew. Its other host includes cotton. It assumes importance during flushing (September- December) and the larvae fold the leaves causing ultimate drying of leaves by its feeding. The moths are dull yellow with brown wavy markings on both the pairs of wings. Females mate a day after emergence and lay eggs two days after mating. A female lays 60-100 eggs singly or in groups on either side of leaves and the incubation period is three to five days. The larva feeds by scraping the leaf tissue remaining inside the leaf fold and when full grown in 22–28 days measures 25–30 mm long. It pupates inside the leaf fold and the adult emerges in six to eight days. Spraying monocrotophos 0.05%, chlorpyrifos 0.05% or endosulfan 0.05% is suggested.

The bark borer *Indarbela tetraonis* (Metarbelidae), the leaf caterpillar *Cricula trifenestra* H. (Saturniidae), the hairy carterpillar *Metanastna hyrtaca* C. (Lasiocampidae), the looper *Oenospila flavifuscata* W. (Geometridae), the tea mosquito bug *Helopeltis antonii* S. (Miridae), the slug caterpillar *Latoia lepida*, the aphid *Toxoptera odinae* and the apple borer *Nephopteryx* sp. *Apion tumidum* D. (Apionidae : Coleoptera) is found as a pest of cashew in Orissa during March-October. The tiny black adults nibble at the growing apical shoots.

4. CASUARINA

The needle of *Casuarina equisetifolia* is bored by the larva of *Eurnenodera tetrachorda* (Cosmopterygidae) leaving the epidermis intact. The other insects attacking casuarina are: *Zeuzera coffeae, Indarbela quadrinotata*, the bag worm *Eumeta crameri* (Psychidae) and the coccid *Naiacoccus serpentinus.* The sapling borer *Sahyadrassus malabaricus* is of minor importance.

5. TEAK *(Tectona grandis)*

Teak is considered to be one of the most valuable timber trees of India. Among the insects that attack teak plantations in South India the two species of defoliators are considered as the most important.

(i) THE TEAK DEFOLIATOR, *Hyblaea puera* Cramer (Hyblaeidae: Lepidoptera)

It is primarily a defoliator of teak occurring abundantly during April-June and occasionally during August-September in South India. The larvae feed entirely on tender leaves and skeletonise the older leaves. There are 12-14 generations in a year. It is reported to be responsible for 44 per cent loss of potential volume growth of the tree.

(ii) THE TEAK SKELETONIZER *Eutectona machaeralis* Walker (Pyralidae: Lepidoptera)

In South India it is abundant in April - May and November. It also feeds on *Callicarpa arborea, C. macrophylla* and *Tectona hamiltoniana.* The larva skeletonises the leaf uniformly. The moth has bright yellow fore wings with pink zigzag transverse markings. The pattern and colour of markings vary depending on season. The moth lays 250–500 eggs singly on leaves and the incubation period is two to threee days. The grown up larva is green with brown or yellow longitudinal bands laterally and measures 22–25 mm long. The larva becomes full-grown in 18–27 days and pupates on the leaf itself or on fallen leaves. The pupal period is 4–11 days. In South India no hibernation occurs in the insect. There are

10-12 generations in a year. As this pest feeds on older leaves towards the end of the growth season no significant impact on tree growth is discernible.

(iii) TEAK BORER *Alcterogystia cadambae* (Moore) (Lepidoptera: Cossidae)

It is an important pest of standing teak trees in Kerala, Tamil Nadu and Karnataka states. It causes extensive bark injury, riddling the bark with numerous holes. The infested tree subsequently gets infected by fungi resulting in the death as well as decay of wood. Usually trees above 15 years old are attacked. Initially the caterpillar feeds on bark and sapwood in the axis of side shoot and then tunnel into the heartwood. The larval stage lasts for about eight months and the larvae pupate in the soil. Presence of bore holes will seriously affect the commercial value of converted teak.

The other species of teak defoliators in South India are *Acherontia lachesis* F., *Psilogramma menepheron* C. (Sphingidae), *Ascotis infixaria* W., *Boarmia fuliginae* Hmpsn., *Cleora alienaxia* W., *Ectropis bhurmitra* W., *Hyposidra successaria* W., *H. talaca* W., *Orsono baclelia* C. (Geometridae), *Dasychira grotei* M., *Olene mendosa* Hubn; (Lymantriidae), *Spilarctia obliqua* B. (Arctiidae) and *Spodoptera litura* (F.) (Noctuidae). The larva of *Labdia callistrepta* Meyr. (Cosmopterygidae) produces brown blisters on upper surface of leaf due to mining under the epidermis. Larva of *Syllepte straminea* B. (Pyralidae) rolls the leaf. The leaf beetles include (*Colasposoma downsei* Baly, *Nodostoma bhamoense* Jacoby (Eumolpidae), *Astycus aurovitatus* H. and *Cyphicerinus tectonae* Mshll. (Curculionidae). *Aularches miliaris* L. and *Teratodes monticollis* Gray (Acrididae) sometimes feed on leaves. The grub of a black or dull brown weevil *Alcidodes ludificator* Faust (Curculionidae) bores through the shoot of teak saplings and kills it. The larvae of *Indarbela quadrinotata* W. and *I. tetraonis* M. (Metarbelidae) are the bark borers on teak. Another borer of teak sapling is *Sahyadrussus malabaricus* (Moore) (Hepialidae). Sap feeding insects noticed on teak are *Otinotus oneratus* W. (Membracidae), *Ptyelus nebulosus* F. (Cercopidae), *Tettigoniella ferruginea* F. (Cicadellidae), the aphid *Aphis gossypii* G. (Aphididae) and the mealy bug *Maconellicoccus hirusutus* G. The inflorescence is damaged by *Leptocentrus vicarius* W. (Membracidae) and the pods and seeds by *Conogethes punciferalis* G. (Pyralidae). The sap wood borers of teak are *Clytus minutus* Gardner and *Xylotrechus quadripes* Cher. (Cerambycidae). The shot hole borers are *Xleyborus andrewsi* B, *X. butamali* B., *X. noxius* S., *X. semigranosus* B. and *X. testaceus* W. (Scolytidae). Teak branches are attacked by the jewel beetle *Psiloptera fastuosa* F. (Buprestidae).

6. SANDAL WOOD TREE (*Santalum album*)

The young saplings are bored by larvae of *Zeuzera coffeae* (Zeuzeridae). The leaves are webbed together by larvae of *Cacoecia micacaeana* (Tortricidae). The foliage is damaged by *Letana inflata* (Tettigoniidae) and is a vector of spike disease of sandalwood. A leafhopper

Jassus indicus (Cicadellidae) attacks tender shoots. The tender leaves are formed into galls due to attack by two species of thrips *Crotonothrips davidi* and *Mesothrips manii.*

7. MAHARUK *(Ailanthus triphysa)*

Among the insects that attack this softwood species the lepidopterous defoliators *Atteva fabriciella* S. (Yponomeutidae) and *Eligma narcissus* C. (Noctuidae) are important. Defoliation by *A. fabriciella* on one to two year old plants causes death of the plants and older plants get weakened. The larvae even feed on inflorescence and seeds. Its life cycle occupies 22-33 days. *E. narcissus* is abundant during September - February.

8. Eucalyptus

The termites *Odontotermes* sp. and *Microtermes* sp. cause more than 90 % damage. The tap-root is ring-barked resulting in death of the affected plant. Drenching the plant with chlorpyrifos 20 EC 50 ml/5 litres of water is recommended. The adults of the beetle *Celosterna scabrator* (Lamiidae) feed on tender shoots and bark up to sapwood and thus kill the shoots or break them outright. The larva bores the stem as well as roots and cause yellowing and wilting. The beetle attacks *Eucalyptus citriodora, E. grandis* and *E. tereticornis.* Adults of *Batocera rufomaculata* (Cerambycidae) have been found to girdle the shoots and cause drying of them. The sapling borer *Sahyadrassus malabaricus* is of minor importance.

9. NEEM (*Azadirachta indica*)

A very common pest on neem trees is the mealy scale, *Pulvinaria maxima.* The tea mosquito bug *Helopeltis antonii* S. infests tender shoots. The thrips, *Megalurothrips chaetogastra* Ramk. infests flowers and leaves and *Dolichothrips indicus* (Hood) the leaves. The seeds are bored by the anthribid beetle *Araecerus fasciculatus* DeGeer.

10. Millingtonia *(Millingtonia hortensis)*

The leaves are damaged by *Acherontia styx* and *Hyblaea puera.*

11. MAHOGANY *(Swietenia macrophylla)*

The shoot borer *Hysipyla robusta* is the major pest and attacks saplings resulting in the death of leading shoot. This has affected the establishment of plantations.

12. ALBIZIA (*Paraserianthes falcataria)*

The bagworm *Pteroma plagiophleps* when infests heavily can lead to growth retardation, die-back and even death of trees. However, it is a sporadic pest. The bark feeder *Indarbela quadrinotata* and the yellow butterfly *Eurema blanda* also attack this tree.

13. SUBABUL (*Lucaena leucocephala*)

The psyllid *Heteropsylla cubana* (Crawford) (Psyllidae). The tree is under serious threat from this exotic psyllid, which sucks its sap damaging young shoots and even suppressing growth of the trees. In Kerala the dragonfly *Pantala flavescens* (Fb.) is predaceous on the psyllid. The other predators recorded in India are: *Irantha armipes* Stal., *Sphedanolestes attrimus* Distant (Reduviidae), *Coccinella transversalis* Fab., *Cheilomenes sexmaculatus* (Fab.) (Coccinellidae). *Lycostomus praeustus* F. (Lyctidae: Coleoptera), *Machimus* sp. (Asilidae), *Adosomyia heminopla* (F.) (Stratiomyidae), *Oecophylla smaragdina* (Fab), *Tetraponera rufonigra* (Jerdon) (Formicidae: Hymenoptera), *Paederus fuscipes* Curtis (Staphylinidae), etc. The exotic coccinellid *Curinus coerulens* was introduced in 1988 for control of the psyllid.

III. PESTS OF SEEDS AND FRUITS

Lasioderma serricorne (Anobiidae) breeds in opium cake, seeds of teak, etc. A number of bruchid beetles attack seeds of *Dalbergia, Acacia, Albizia, Tamarindus indicus,* etc. *Calandra rugiocollis* (Curculionidae) bores the seeds of *Dipterocarpus* spp., *Eugenia, Polyalthia* and *Shorea robusta.* The seeds of *S. robusta* are also attacked by *Diplophyes shoreae* (Curculionidae). The pyralid larva *Hypsipyla robusta* attacks the fruits of *Cedrela toona* (toon fruit borer) in North India.

IV. PESTS OF FOREST PRODUCTS

Product	Pest
Bamboo	*Dinoderus minutus*, *Chlorophorus annularis* (Cerambycidae)
Boxes, chests & plywood	*Heterobostrychus aequalis*
Match veneer & plywood	Powder post beetle, *Lyctus africanus* (Bostrychidae)
Timber Structure	*Xyleborus* spp., *Stromatium barbatum*, *Camptorrhinus mangiferae* (Curculionidae) *Heterotermes indicola* (Rhinotermitidae)

◆ Chapter 75

Medical Entomology

Besides the cultivated crops and the stored crop produce stored, farms, domestic animals, and forest trees, the other important group of life attacked by insects is man himself. Insects attack man in a number of ways. Some simply annoy him and some others directly injure him for his blood while a few, in the process, transmit various kinds of diseases to him.

1. Mosquitoes

Both sexes of the mosquito feed on various juices of fruits and flower nectar but the females take also meals of blood after inflicting a painful bite on human beings. Mosquitoes are well known vectors of four distinct human diseases. The adults of anopheline mosquitoes rest with proboscis and abdomen more or less parallel with surface. Dr. Ross in 1897 demonstrated that the *Anopheles* mosquito is the transmitter of malaria. The principal vectors in India are *Anopheles culicifacies, A. fluviatilis, A. stephensi, A. minimus,* A. *sudanicus, A. philippinensis* and *A. varuna,* out of which the first three species are the major vectors found in South India. *A. fluviatilis* is the main vector in hilly areas and *A. stephensi* in urban areas. Among culicine mosquitoes there are two groups viz., *Culex* group and *Aedes* group. In the *Culex* group eggs are laid in rafts and the siphon tube of the larvae is long. In *Aedes* group the eggs are deposited singly and the siphon tube is short and broad. *Culex fatigans*, found in urban areas in India, is the principal intermediate host of the filarial nematode *Wuchereria bancrofti*. The egg raft of *C. fatigans* is boat shaped with about 200 eggs. Breeding is heavy in waters contaminated with sewage. The transition from egg to adult takes 8-10 days. The exact mode of transmission was described by T.L. Bancroft, who observed that the microfilaria required about 16-17 days in the mosquito before it could reach the infective stage. Human infection occurs at the time of biting. Species of *Mansonioides* are responsible for transmission of *Brugus malayi*. The larvae of this mosquito are associated with aquatic plants like *Pistia* and removal of these plants will at once stop their breeding. Both *W. bancrofti* and *B. malayi* may occur in the same individual. When the mosquito bites a man, the larvae are inoculated into the tissue. The minimum microfilaria density sufficient for infection of mosquitoes is important in order to determine the efficiency of certain drugs like Hetrazan in rendering persons harbouring microfilaria non-infective to the mosquitoes. The minimum number appears to be 3 per c.mm of blood. Monsoon weather is the most favourable one for the transmission of filariasis. Mosquitoes of the genus *Aedes* are responsible for transmission of the causative agents of two important diseases of man viz., dengue and yellow fever. The eggs are deposited singly and the larvae possess a short and broad siphon tube. Graham in 1905 was the first to prove the mosquito-transmission of dengue. In 1906, Bancroft from Australia proved that *Aedes aegypti* (Fig. 75.1) is the carrier of Dengue.

▲ **Fig. 75.1** *Aedes aegypti*

The blood of a dengue patient is usually infective to the mosquito only during the first three days of the disease. The incubation period for the development of the virus in *A. aegypti* is 11–14 days and once infected, the infection lasts during the remainder of its life. *A. aegypti* is also the vector of the disease yellow fever. The infective material of yellow fever circulates in the blood of the patient for the first three days and during this time mosquitoes feeding on the patient become infective. It takes about 12 days before the mosquito is able to propagate the disease to non immunes.

Control: Larvae may be killed by the application of DDT. But as mosuqitoes have developed resistance to organochlorines use of safer chemicals has been taken up. Application of fenitrothion at 0.5 g to 1.0 g a.i. /sq. m. on the surface of mosquito breeding water has been found to be effective up to six and ten weeks, respectively. Fenthion and malathion have also been reported to be effective. Use of mosquito nets of 16 meshes/sq. inch in houses and repellents like citronella oil, etc. may be followed. Commercial products based on DEET (N, N-diethyl m-toluamide) or DEPA (Diethyl Phenyl Acetamide) are available as mosquito repellents. Space sprays of DDT, fenitrothion, fenthion, propoxur, deltamethrin etc. may kill adult mosquitoes, which come to rest on the treated surfaces. Good results have been obtained by impregnating bed nets with deltamethrin 2.5% or lamda-cyhalothrin @ 25 mg/sq. m. or cyfluthrin at 50 mg /sq. m. A water dispersible formulation of *Bacillus thuringiensis* var. *israelensis* serotype H14, strain 164 is highly effective against early instar mosuqito larvae when applied at 0.5 g/sq. m. of water surface or at 0.5% suspension by knapsack sprayer at two to six weekly intervals. *B. sphaericus* is also effective against mosquito larvae. Aerosols for control of mosquito adults include propuxur 0.75% + cyfluthrin 0.025% and cyfluthrin 0.025% + transfluthrin 0.04%. Mosquito mats containing prallethrin 0.5% is also useful as a control measure against mosquitoes.

2. The Housefly *Musca domestica* (Muscidae : Diptera)

The housefly is associated with the spread of the diseases like typhoid fever, cholera, diarrhoea, dysentery, intestinal worms, poliomyelitis, leprosy, anthrax, yaws, etc. The causative organisms of the diseases are picked up by the flies from the human excrements, sputum, carcasses of diseased animals, manure and other filth. They may be carried on the mouthparts, legs, wings and body surface of the housefly.

Control: Keeping the surroundings clean and neat; storing food materials in housefly proof enclosures or boxes, setting baits with milk and formalin for adults flies; surface spray application of propoxur or 125 mg etofenprox is recommended. Aerosols for control of housefly include propuxur 0.75% + cyfluthrin 0.025% and cyfluthrin 0.025% + transfluthrin 0.04%.

3. The Eye-fly *Siphunculina funicola* de Meij (Chloropidae : Diptera)

The minute bluish-black fly generally settles on the face especially on the corners of the eyes of persons with eye complaints and thus cause annoyance. It is commonly seen to congregate in large numbers on threads or ropes hanging from roof in houses in damp warm places. Conjuctivitis is believed to be transmitted by the fly. Surface spray application of propuxur or etofenprox on resting places of the fly may be useful.

4. Sand flies *Phlebotomus* spp. (Psychodidae : Diptera)

The flies are small with the body and wings thickly covered with hairs. The females of Psychodinae are blood-suckers and transmit kala-azar disease caused by *Leishmania*, a flagellate which is spread by *Phlebotomus argentipes*. *P. pappatasi* transmits the Pappatasi fever prevalent in India. Verruga disease in Peru is transmitted by a species of *Phlebotomus*.

5. The *Simulium* or Black flies (Simuliidae : Diptera)

The females are vicious biters and suck blood mostly of cattle. Some species attack man. Eggs are laid on aquatic plants submerged in water. The larvae occur in swiftly running streams fixing themselves to stones or plants at about 30 cm depth. Human onchocerciasis caused by the nematode *Onchcerca volvulus* is transmitted by *Simulium damnosum*. The disease occurs in tropical Africa, Arabia, and central America. *Simulium indicum* is troublesome in Himalayas.

6. Bed bug *Cimex hemipterus* (Cimicidae : Hemiptera)

The venom introduced by the bed bug bite causes itching, burning and swelling. They are parasitic on man and suck his blood. A large number of diseases like relapsing fever, typhus, kala-azar, plague, leprosy, etc. have been suspected of being carried by bed bugs but not proved. A female lays about 50 eggs singly in about four months in cracks, crevices, furniture, mattress, pillows, etc. The egg is white and flask-shaped. The incubation period is four to five days during summer and 10 days during winter. The bed bug feeds intermittently by sucking blood from man. There are four nymphal stages, each stage lasting for five to seven days. The bed bugs are disseminated mainly through the agency of personal clothing. *Cimex hemipterus* is the principal species in the tropical countries and *C. lectularus* in the temperate countries (Fig. 75.2).

▲ **Fig. 75.2** *Cimex lectularius*

Control: White washing and closing the crevices of walls, application of boiling water on furniture which can withstand high temperature, and surface spray application of fenitrothion, propoxur, etc. may be useful in controlling bed bugs.

7. The Assasin bug *Conorhinus rubrofasciatus* (Reduviidae : Hemiptera)

It is also known as Cone Nose bug or Kissing bug. It is dark brown, 20-24 mm long and is found hiding in crevices or under stones. It attacks both man and other insects. The pain caused to human beings is intense and swelling generally follows. Fainting, vomiting and other ill effects may be experienced. Usually they bite man at night for blood meal. Collection and destruction of the bugs may be done.

8. Fleas *Pulex* spp. and *Xenopsylla cheopis* (Pulicidae : Siphonaptera)

Fleas in their adult stage live as ectoparasites of warm-blooded animals. They infest dogs, cats, human beings etc. Its bite is not felt at once but becomes increasingly irritating and sore over several days. Bubonic and septicaemic plague is the principal disease carried by rat flea, *X. cheopis.* The causative organism of plague is the bacillus *Pasteurella pestis. Xenopsylla cheopis* is widely distributed in the tropics and in India it is widely prevalent in the plains and also in the hilly regions. *X. brasiliensis* is another plague flea found in India and Africa. *X. astia* is also prevalent all over India. *Pulex irritans* is essentially a human flea and *Ctenocephalides canis* and *C. felis* are dog and cat fleas, respectively. The flea is apterous and its body is heavily chitinised and laterally compressed. *X. cheopis* and *X. astia* lay about six to eight eggs after a blood meal and the eggs are deposited in places where the host rests. A female lays about 200 eggs in her lifetime. The larvae feed on a variety of organic material. The flea is parasitic only in its adult stage. Both the sexes feed on blood and may leave the host between feeds. Only during an epizootic of plague among rats they attack man.

Control: Dead rats should not be handled and should be burnt by pouring kerosene. The breeding places should be treated with propoxur for controlling the fleas.

9. Human body louse *(Pediculus humanus humanus)* and Head louse *(P. humanus capitis)* (Pediculidae : Siphunculata)

Both the lice can transmit relapsing fever, epidemic typhus fever, French fever, etc. They also cause lot of irritation by their bites. The skin becomes scarred, thickened and bronze-coloured with brownish spots. The head louse is found on the skin and among the hairs of the head. It glues its oval, pearly-white, eggs singly to hairs. The body louse is found in the clothing and lays eggs in seams of the clothing. About 300 eggs are laid by a louse.

Control: Hair must be combed and lice collected and killed. The infested head should be treated with pyrethrin in pyrophyllite or commercial preparations such as Kenz containing gamma HCH.

◆ Chapter 76

Veterinary Entomology

As if they are not content with the damage they cause to growing crops and stored crop produce, and with the various diseases they transmit to crops cultivated by man, insects attack all animals domesticated and reared by him. This variety of insect pests not only cause direct injury and annoyance to these animals but also, in some cases, cause and transmit diseases and functional disorders in them. The productivity of the affected animals is impaired and the utility of farm animals is reduced resulting in huge aggregate yearly losses. The insect pests of cattle and other domestic animals are mostly members of Diptera and some are of Mallophaga, Siphunculata and Siphonaptera. They attack cattle, sheep, goats and fowl.

I. CATTLE

1. THE HORSE FLY *Tanbanus striatus* F. (Tabanidae : Diptera)

It resembles the housefly but is larger and stouter, has three rows of white spots on the abdomen and prominent compound eyes, almost contiguous on the vertex in males. The fly breeds in marshy places. Eggs are black and elongate, spindle-shaped and are glued in masses to aquatic plants. The maggots are elongate, spindle-shaped and carnivorous; they drop to the substratum where they live feeding on small aquatic organisms. The female fly pierces the skin of animals and suck the blood, which continues to ooze from the wounds even after the fly has left the animal. The male feeds upon nectar of flowers. On an animal 50 or more tabanids may be found in an hour. Life cycle is four to five months and there are two to three broods in a year.

2. THE STABLE FLY *Stomoxys calcitrans* (L.) (Muscidae : Diptera)

It is a cosmopolitan species. The grey fly can be distinguished from the houseflies by its somewhat smaller size, long proboscis adapted to pierce the skin and seven spots on the abdomen. It breeds in moist straw, grass and other material in the cattle shed, to which urine and dung of the hosts get added. The fly is usually abundant after rain. Both females and males suck blood from cattle, horses and other animals including man, usually from his legs and get engorged in two to five minutes and may feed as often as twice a day. A female lays 600-800 eggs. Its life cycle occupies 10-14 days.

3. THE CATTLE FLY *Hippobosca maculata* L. (Hippoboscidae: Diptera)

It is a flat fly with a leathery thick-set body and strong tarsal claws. It can always be seen on cattle clinging mostly at the sides of the neck region. It feeds on the blood continuously and produces seed-like puparia directly, without laying eggs or larvae; the puparia drop to the ground and adult flies emerge in a week.

All the above three flies can be controlled by use of deterrents. Application of fenitrothion 50 % EC @ 100 ml in 10 litres of water or deltamethrin 2.8% EC @ 2 ml/litre water has been reported to be effective. The animals may be sprayed individually taking care to treat the tip and under portion of the tail; inside the ear and folds of legs. For prolonged residual effect washing of the animals should be avoided for a few days after the spraying. Spraying may be repeated at an interval of four to five weeks.

4. THE BLOW FLY OR BLUE BOT FLY *Lucilia serenissima* E. (Calliphoridae: Diptera)

It is a metallic blue or green coloured small fly whose larvae attack open wounds and sores of cattle and feed on decaying tissues. It also bores into flesh causing cutaneous myiasis and other internal complications. At times they may be useful because they clean wounds of dead tissues.

5. THE OX WARBLE FLY *Hypoderma lineatum* (deV.) (Oestridae: Diptera)

The female fly lays eggs glued to the hairs near the hooves in cattle. They hatch in two to three days and the maggots penetrate into the skin tissues and live for several weeks. They move to oesophageal wall and then reach the subcutaneous tissue on the back of the animal where they form tumour-like swellings or warbles. The skin of the warble is perforated by the larvae for respiration and later through these holes the full-grown larvae fall to the ground for pupation. Adult flies emerge after three weeks. As the skin is drilled and bored, the hide becomes unmarketable. The fly can be controlled by washing the warbles with water infusions of lime and tobacco.

6. THE HOUSEFLY *Musca* spp. (Muscidae : Diptera)

Out of the many species of *Musca* a few are blood sucking and the rest are non-biting but are of considerable nuisance value to animals. *Musca domestica* L., *M. nebula* F., *M. vicina* Macq., and *M. sorbens* Weld. are non-biting flies. The fly breeds in a number of decaying material including cattle dung and night soil. A single female lays up to 200 eggs during her life span and the eggs hatch within about three hours. The full-grown maggots pupate in damp soil. The houseflies are carriers and intermediate hosts of many cattle diseases. Another species of *Musca* viz. *M. crassirostris* Stein is haematophagous, breeding on cattle dung, biting and sucking blood from cattle. The spray schedule suggested for control of the cattle fly may be useful against this fly also. Spray of etofenprox 10 EC @ 125 mg a.i./sq. m. in cattle shed is effective against adults.

7. THE BLOOD-SUCKING FLY *Siphona exigua* de Meijere (Muscidae: Diptera)

It is a common blood-sucking fly in India, which attacks cattle, buffalo and dog. It is attracted by the odour, warmth and sweat of its host. Both sexes are blood suckers. The fly lays eggs in fresh cow dung and a female lays about 20 eggs. The incubation period is about 10 hours. The maggot becomes full-grown in about seven days and pupates in the soil some distance away from the dung. The adult fly emerges in four to five days.

8. SAND FLIES *Phlebotomus papatasi* (Psychodidae : Diptera)

Sand coloured females of *Phelbotomus* suck blood. Each female lays about 30 eggs in damp places. Incubation period is about 10 days. Larval stage lasts for 20 to 50 days and the pupal stage for a week. Species of these flies are known to transmit various diseases like kala-azar or leishmaniasis in man.

9. THE EYE FLY *Siphunculina funicola* de Meij. (Chloropidae: Diptera)

They are shining black in colour usually seen clinging in clusters on hanging strings in houses and cattle sheds. They hover in front of the eyes and feed upon the secretions from the eye. They breed in moist soil and faecal matter.

10. EYE FREQUENTING MOTHS

A few moths are known to frequent the eyes of vertebrates and mention may be made of the following. The moths of *Arcyophora icterica* (Noctuidae) frequent the eyelids of cat, cattle, waterbuffalo, horse and donkey in South India and feed on lachrymation and pus. The moths of another species *Pionea damastesalis* Walker (Pyralidae) are known to visit the eyes of cattle, waterbuffalo and elephant and also that of man for feeding on lachrymation, besides feeding on fluid running down the cheeks of the animals.

In addition to the above insect pests, females of various species of the stout black gnats (Simuliidae : Diptera) which breed in swift running water streams, the mosquitoes

(Culicidae : Diptera) and the midge, *Culicoides* sp. (Ceratopogonidae : Diptera) annoy cattle and suck blood from them.

II. FOWL

1. THE SHAFT LOUSE *Menopon gallinae* (L.) (Menoponidae : Mallophaga)

It is a permanent ectoparasite of fowl found on their feather feeding by nibbling on the dry scales of the skin and chewing the feathers. Badly infested birds can be observed rubbing their bodies in soil or ash pits to get rid of the annoyance caused by these lice. The louse is small, wingless, very active, greyish brown in colour with a hard and horny body with mandibulate mouthparts. The eggs are fastened to the basal barbs in large numbers. The yellowish nymphs hatch out in two weeks. They become adults in 10- 12 days. The louse spends its entire life cycle on the host bird itself.

2. THE BODY OR VENT LOUSE *Menacanthus stramineus* (Nitz.)(Menoponidae : Mallophaga)

It is one of the commonest ectoparasites of poultry. It congregates on the skin just below the vent and in cases of severe infestation may be present on the ventral side under the wings. It is very destructive.

3. THE WING LOUSE *Lipeurus caponis* L. (Philopteridae : Mallophaga)

It infests the underside of the primary feathers and does not move about a great deal.

4. THE CHICKEN FLEA *Echidnophaga gallinacea* (W). (Tungidae : Siphonaptera)

The flea infests the face, comb, wattles and area around the eyes of fowl in clusters. Sometimes hundreds of these insects may be seen on a single bird. When heavily infested young birds die and older ones get emaciated. It is a minute, flat, dark brown insect remaining attached to the host with its head embedded into the skin of the host, so that it is not easily brushed off. The eggs of the flea drop to the ground where the larvae develop in the filth. Only the adult fleas attack the birds.

Control: For the control of poultry lice and chicken flea spray application of the birds in batches of 10- 12 birds at a time with fenitrothion 0.25 per cent solution to the point of drenching has been found useful. The spraying should be repeated at intervals of three months. Care should be taken to avoid contamination of poultry feed and water.

5. THE MOSQUITOES *Aedes aegypti* (L.) (Culicidae : Diptera)

It transmits malaria in fowls caused by *Plasmodium gallinaceum.*

6. BED BUG *Cimex hemipterus* Fab. (Cimicidae : Hemiptera)

The bugs suck the blood from the birds at night. Both adults and nymphs feed on the birds and cause loss in egg production as the birds get emaciated. Spraying the infested premises with 0.5 % fenitrothion or deltamethrin 25 ppm controls the pest. There is no need to spray the birds as the bug attacks the birds only at night. The spraying should be repeated after about three weeks.

III. SHEEP AND GOATS

1. THE HEAD MAGGOT OF SHEEP *Oestrus ovis* L. (Oestridae : Diptera)

This larviparous fly deposits the maggots in the nostrils of sheep. The maggots move to frontal sinuses resulting in constant nasal discharge and sometimes obstruction of air passages in the affected sheep. In serious infestations the sheep may die.

2. THE SHEEP KED *Melophagus ovinus* L. (Hippoboscidae : Diptera)

It is a wingless, leathery, hairy fly attacking the sheep in different parts of our country. The female glues its larvae to the wool of sheep. They soon turn into pupae. The adults live among the wool and suck blood causing intense irritation prompting the sheep to bite the area thus damaging the wool. Spraying with 0.01 % diazinon or deltamethrin 25 ppm will eliminate the ked.

3. THE BITING LOUSE *Bovicola caprae* (G.) (Trichodectidae : Mallophaga)

Commonly occurs in goats and *B. ovis* in sheep. Dips containing 0.01 % diazinon or deltamethrin 2.8% EC @ 3 ml litre water i.e. 37.5 ppm can be employed for controlling these lice.

General Control Measures

The treatment solution should be prepared just before use. A quantity of 3.5 litres may be required to make a medium size cattle fully wet. For dogs the hand spray can be used or its body rubbed with a cloth dipped in the solution. Spray the recommended chemicals in poultry sheds, stables and farm houses for ectoparasitic control. One litre of spray fluid should suffice for 20 sq. m. area.

◆ Chapter 77

Insect Pests of Household

Insects are known to frequent our dwellings, fall accidentally into our eyes, rest on sensitive parts of our body, make irritating noise and damage our food materials, cloths, carpets, furniture, books etc. due to their biting and feeding and cause annoyance to us. The following are some of the household insects.

1. ANTS *Monomorium criniceps* and *M. destructor* (Formicidae : Hymenoptera)

The former is a small brown ant and the latter is a small red ant. Everyone is familiar with the house ants, which carry bits of our food materials to their nests. There are also some species which are injurious because they build nests in the sills and wood work of houses. The species that are found in lawns and walks in our house gardens throw mounds of earth about the entrance to their nests and thus disfigure the lawn. Some species feed on seeds, fats, dead insects, etc.

Control: Ant pans can be used where ever feasible. Dusting carbaryl 10 % or spraying 2 to 5 % solution of chlorpyrifos in deodorised kerosene in infested area may afford relief. Poison baiting with thallium sulphate bait for sweet loving ants and with thallous sulphate bait for protein loving ants may be useful.

2. TERMITES

Termites feed on wood, paper, wood products, dried plant and animal products, etc. Among termites we have the soil inhabiting forms and the wood inhabiting forms, the later damaging dry and damp woods. To prevent infestation by subterranean termites, having any wood work of buildings within 40 cm of contact with the ground should be avoided. A thin sheet of metal or good concrete between the foundation and timbers of the house will prevent infestation. Termite proofing of wood can be done by pressure impregnation with coal tar, creosote, zinc chloride, mercuric chloride, sodium fluosilicate, chlorpyrifos, lindane etc. after the wood is cut. Soil poisoning with chlorpyrifos in kerosene may be done. For protection of wood and buildings (pre/post construction) from termites attack lindane 20% EC or chlorpyrifos 20 EC @ 250 ml diluted in 5 litres water is applied.

3. POWDER POST BEETLES

The furniture beetle *Sinoxylon sudanicum* (Bostrychidae: Coleoptra) and some other species of Lyctidae, Ptinidae, Anobiidae and Bostrychidae are also destroyers of wood. The grubs cut the hard and dry wood tunneling through timbers in successive generations until the interior is completely reduced to fine packed powder. Small shot holes are visible externally. They are often responsible for destruction of timbers of buildings, log cabins, furniture, tool handles, etc.

Control: Wood may be preserved by treating it with copper sulphate or zinc chloride. Drying the wood at 82°C for half an hour kills the insects. Fumigation with methyl bromide can be done where ever feasible. Painting the wood with varnish, paint, tar, etc. keeps the wood free of attack.

4. SILVER FISH *Ctenolepisma* sp. (Lepismatidae : Thysanura)

The insect is found commonly in neglected places on walls. It feeds on a large variety of materials such as starched clothes, rayon fabrics, bindings of books, papers on which paste or glue has been used, etc. The insect is wingless, 8 - 13 mm long, silvery greenish grey or brownish and sometimes faintly spotted; lives in warm places and avoids light. The eggs are deposited loosely in secluded places and the incubation period may be about a week. The adult stage is reached in 3 to 24 months. The insect can be controlled by surface spray application of propoxur at 0.5 % strength. Poison baits consisting of oatmeal, sodium fluoride or white arsenic, sugar and common salt may also be useful.

5. COCKROACH *Periplaneta americana* (Blattidae : Dictyoptera)

The cockroach is a common insect found in almost all houses. The insect is flat, brownish and foul smelling. It is active at night or in dark basements and feeds on bindings, magazines, paper coverings of boxes, various food products in kitchens, bakeries and restaurants and produces foul smell with the excreta spread over. The female cockroach produces an ootheca once in four or five days and 15 to 90 oothecae may be laid. Each ootheca contains 14 to 16 eggs and the incubation period ranges from 15 to 100 days. The nymphal period occupies 10 to 16 months. Dust of propuxur, a carbamate insecticide, if spread all over infested places, affords effective control of cockroach. Surface spray application of propuxur is also effective. Etofenprox (1 mg per sq. cm.) spray application is highly effective against German cockroach *Blattella germanica* (Fig. 77.1). Scrupulous cleanliness to keep away the insect is essential. Deltamethrin 0.5% w/w attractant tablet for cockroach has been developed. Aerosols for control of cockroaches include propuxur 0.75% + cyfluthrin 0.025% and cyfluthrin 0.025% + transfluthrin 0.04%.

▲ **Fig. 77.1** *The German Cockroach Blattella germanica*

6. CARPET BEETLE *Anthrena pimpinella* (Dermestidae : Coleoptera)

The larvae and adults of the beetle bite holes in fabrics like wigs, clothings, curtains, interior padding of furniture, etc., which contain especially wool, fur, feathers and hairs. They also attack cotton goods, silk, insect specimens, stuffed animals, dried meat, etc. The eggs are deposited in dark secluded places or on fabrics. The larva possesses erect, brown or black hairs all over its body. Regular cleaning of materials is essential. Godowns where fabrics and other material are stored should be fumigated. In small enclosures or boxes use of paradichloro benzene crystals or napthalene balls may give relief.

7. CLOTHES MOTHS *Trichophaga abruptella* (black and white moth) and *Tinea pachyspila* M. (brown moth) (Tinaeidae: Lepidoptera)

The larvae attack mainly wool, hair, feathers and furs and sometimes damage dead insects, dry dead animals, animal and fish meals, milk powders, leather, etc. The control measure suggested for carpet beetle may hold good for this also.

8. CRICKET *Gryllus* sp. (Gryllidae : Orthoptera)

The crickets live in the crevices and the males mainly cause annoyance by making chirping noise at night by rubbing the wings together. They can be easily located, collected and destroyed.

◆ Chapter 78

Insect Vectors of Plant Diseases

Insects are involved in the transmission of bacterial, fungal, viral and phytoplasmal diseases of plants, besides affecting humans and animals in serving as agents in the transmission of diseases. Transmission may be *mechanical,* the organism being borne on the surface of the body of the insect, usually the mouthparts. Transmission may be *circulatory* when the organisms are ingested by the insect, circulate in the body and are later discharged in the salivary fluids. Transmission may be by *inoculation* in the case of sucking insects where through a wound made by the insect, the pathogens invade the tissue. The relationship may be *obligate* when the pathogens are transmitted by inoculation or *facultative* wherein the pathogens can be transmitted in other ways. In short, an insect whose feeding produces symptoms of disease is termed *toxicogenic* and the condition is called *phytotoxaemia.* Insects, which transmit disease organisms are called *vectors* and a variety of insects, mostly with sucking mouthparts may serve as vectors of plant diseases.

The insect vectors provide a versatile means of spread achieving an effective distribution of inocula. The modus operandi of exploitation by vectors is essentially achieved by their polymorphism which involves the production of diverse adult forms of contrasting behaviour, such as alate/ aptera, or macroptery/brachyptery/microptery, colour diversity, sex-limited polymorphism and biotic potential, besides the comparative ability of both sexes and morphs to transmit the virus. The role played by seasonal, photoperiodic endocrine and crowding phenomena in the production of different forms, notably in aphids is an aspect that has to be recognised, more in view of the vector role of aphids. Operation of switch mechanisms induced by photoperiodic responses and endocrine influences produce sexual/ parthenogenetic and alate/ apterae respectively, besides the maternal switching mechanisms wherein generations of parthenogenetic viviparae have embryos telescoped. Moreover within every species a range of biotypes exists, each with its own vector capacity, responding differently to environmental stimuli and have the capacity to settle on different plant genotypes besides their different nutritional requirements enabling them to respond differently to host plants.

Many cicadellids feed on cereals and grasses and have two contrasting types of spreads i.e. the long fliers with short bodies predominating the main flight period, and short fliers with relatively long bodies. Short-bodied forms are less fecund. Field populations are known to have a balance of long bodied poor fliers suited for dispersal to favourable habitats. This type of structural and behavioural polymorphism has obvious survival value for leaf hoppers facilitating colonisation and subsequent exploitation provides an efficient means of virus spread.

When a virus is widespread in several crops and perennial plants, and when spread by several vectors such as aphids, the complexity of the ecological interactions become great. For e.g., *Rhopalosiphum maidis, R. padi, Schizaphis graminum,* etc. which are major vectors colonising cereals have different biologies. For instance one may be monoecious and holocyclic, another heteroecious and heterocyclic, and the third may be anholocyclic. In *R. maidis* four different biotypes are known with varied ability to transmit the virus and these have different modes of virus spread depending on the physiological status of the insect vector. These different types of virus spread lead to different patterns of spread requiring a different management strategy.

Even colour differences have their own impact as for instance the pale form of the thrips, *Frankliniella schultzei,* the vector of TMV is not being able to transmit the virus, unlike the darkened forms. Colour morphs of several aphid species, which can range from green to brown, passing through a range of pink and red, have shown green forms to be more fecund with high rates of parasitism. Hence without an understanding of the structural and behavioural diversity of vectors, their movement, their ability to travel, their feeding and reproduction and what cause them to settle down, feed and reproduce, it would be difficult to explain the progress of epidemics, so that merely designating a species as a vector is often misleading. Therefore, there is great need to understand the occurrence and significance of biodiversity within vector populations. A basic factor is that colonising forms are partially active, seldom settle down to feed and reproduce until dispersal has occurred.

Infected plants are known to be attractive or palatable to vectors and this stimulates increased multiplication and crowding. This follows movement from crowded populations that develop on ripening crops, weeds and other wild plants, as these begin to senesce.

Long range viral dispersal occurs in such circumstances, so that a close association between virus spread and migration exists, and thus the breeding population gets transferred to fresh sites before original site becomes unpalatable. The relationship between the insect vector and the host plant of the virus needs to be understood. The diseased plant being an altered host, little is known of specific changes occurring in plant cultivars, under insect feeding stress and their subsequent effects on vectors. Increased amino acids in infected plants/senescent plants may be detrimental to some and in response to deterioration of host quality nitrogen (N) levels fall resulting in the production of alates in aphids, which migrate to secondary hosts. Some viruses that replicate in the vectors have shown much deleterious effects on fecundity/longevity that they are likely to impair mobility and flight performance. It is important to monitor the distribution and spread of vector biotypes, as increasing number of vectors develop tolerance to pesticides and overcome host plant resistance mechanisms.

Non-culturable plant infecting molecules are designated as Phytoplasmas (mycoplasma-like organisms) and are grouped in between viruses and bacteria. They are without a visible cell wall, whose place is taken by a thin elastic cytoplasmic membrane, which cannot withstand osmotic pressure. They are pleomorphic and may be spherical or oval, varying from 80-800 microns in diameter.

An aspect of interest relates to thrips - fungal interactions, wherein sex-limited polymorphism plays an important role in the increased mechanical transfer of pathogenic fungal spores to many forest plants. The array of male polymorphs from the gynaecoid to the oedymerous males enable transport of spores of pathogenic fungi such as *Anthostomella, Pestalotia, Malanographium, Phomopsis* and *Lasiodiplodia* to sites of infection.

In view of the very large number of plant diseases caused by insect vectors, the table presented provides information on the more important ones.

Diseases	*Vectors*	*Host plants*
1. Virus diseases		
Cucumber mosaic	*Myzus persicae*	Cucumber and weed plants
Sugarcane mosaic	*Rhopalosiphum maidis*	Sugarcane, Sorghum, corn, millet
Spotted wilt	*Thrips tabaci*	Tomato
Tomato mosaic virus (TMV)	*Frankliniella schultzei*	Tomato
Potato leaf roll	*Myzus persicae*	Potato and other solanaceous plants
Cowpea mosaic	*Aphis gossypii*	Cowpea
	Aphis craccivora	Cowpea
Banana Bunchy top	*Pentalonia nigronervosa*	Banana
Cardamom mosaic ('Katte' disease)	*Pentalonia nigronervvosa*	Cardamom

Diseases	*Vectors*	*Host plants*
Papaya mosaic	*Aphis gossypii*	Papaya
	Aphis craccivora	Papaya
Chilli mosaic	*Aphis gossypii*	Chillies
Vein clearing disease	*Bemisia tabaci*	Lady's finger (Okra, Bhendi)
Dolichos Yellow mosaic	*Bemisia tabaci*	Lab-lab bean
Tobacco leaf curl	*Bemisia tabaci*	Potato
Tomato leaf curl	*Bemisia tabaci*	Tomato
Papaya leaf curl	*Bemisia tabaci*	Papaya
2. Phytoplasma diseases		
Rice yellow dwarf	*Nephotettix virescens*	Rice
'Little leaf' disease	*Cestius phycitis*	Brinjal
Sesamum phyllody	*Orosius albicinctus*	Sesamum (Gingelly)
3. Fungal diseases		
Ergot of Cereals *(Claviceps purpurea)*	Many flies	Cereals
Ergot of Bajra *(Sphacelia macrocephala)*	Insects	*Pennisetum typhoideum*
Cotton wilt *(Fusarium vasinfectum)*	*Melanoplus differentialis*	Cotton
4. Bacterial diseases		
Bacterial wilt of corn (Stewart's disease)	Flea beetles *Chaetocnema pulicaria , C. denticulata*	Corn
Cotton boll rot (*Bacillus gossypiana)*	Hemiptera	Cotton
Cucurbit wilt	*Erwinia*	Cucurbit

Section Nine

Methods and Principles of Pest Control

◆ Chapter 79

Integrated Pest Management

Insect control programmes aim at avoidance, elimination or reduction of the factors, which promote excessive multiplication of insects. For the efficient functioning of insect control measures, a thorough knowledge of their life cycles, their pest status, distribution, periodicity, host-complex, behaviour among others, is a prerequisite, essential for timing of the controls. As the economics of the control methods adopted is equally vital, any measure devised has to be practical, cheap and effective.

It is usual to broadly classify insect control methods into the natural and applied or artificial control methods. As has already been discussed under population dynamics, natural control methods involve such factors as climate including in it directly or indirectly the effects of temperature, humidity, rainfall of a region, soil conditions and nature of wind currents; topographic factors, including barriers like mountain ranges, large bodies of water, thick forests restricting the spread of insects; and natural enemies like the predators and parasites which increase with the increase of populations of insect pests.

Applied or artificial control methods are mostly divided into the preventive and curative or direct methods. Preventive or prophylactic methods to ward off pest invasions include measures such as the removal of weeds, grasses and dead branches from fields; through usage of good seeds, proper cultivation, manuring, irrigation, removal of crop remains and stubble, growing of pest resistant varieties, treatment of seeds with chemicals, rotation of crops, mixed croppings, changing of the sowing, planting and harvesting times, cutting and raking of field bunds etc. Among the direct methods are the physical and mechanical methods. The physical methods involve the use of electricity, sound waves, infra-red and X-rays. The mechanical method is concerned with the operation of machinery such as hopper dozers, fly and maggot traps, light traps, centrifugal force machines (entolete) for stored grains and manual operations involving the hand picking of egg masses, larvae and adults. Chemical methods include the use of insecticides, repellents and attractants, antifeedants and chemosterilants. Another aspect of control is the legal or legislative method. In order to prevent the introduction of exotic pests, diseases, weeds, etc. with a view to help in the prevention of their spread within the country, special acts or laws are enforced. In addition to prevention of spread of pests, they also serve to help in the correct determination of insecticidal residue tolerance in food stuffs, in the prevention of adulteration and misbranding of insecticides and regulate the activities of pest control operations, particularly in the application of hazardous insecticides. It may be of interest to point out that the then Madras State (presently Tamil Nadu) was the first to enact the Agricultural Pests and Diseases Act in India in 1919 for the control of the black-headed coconut caterpillar (*Opisina arenosella*), the cottony cushion scale (*Icerya purchasi*), the coffee borer (*Hypothenemus hampei*), the sugar cane top borer (*Scirpophaga excerptalis*), the cotton boll worm (*Earias* spp. and *Pectinophora gossypiella*), the red hairy caterpillar (*Amsacta albistriga*) on groundnut and the coffee stem borer (*Xylotrechus quadripes*).

The need for a reduction in the use of pesticides in view of environmental and health concerns, besides a more effective insect pest management, led to the emergence of a new perspective in pest control called Integrated Pest Management (IPM). It aims to make crop production more efficient, while seeking protection from misuse of pesticides. In this context, populations of insects are monitored and pesticides applied only when and where they are needed to control specific insects in specific crops at specific times. In a broad sense IPM has been defined as "the optimisation of pest control in an economically and ecologically sound manner, accompanied by the coordinated use of multiple tactics to assure stable crop production and to maintain pest damage below the economic injury level, while minimising the hazards to human, plants and environment". IPM must be visualised in terms of agroecosystem management with farms considered as ecosystems. A better understanding of factors affecting ecosystem stability, population dynamics of pest species and the ability of population to recover from stress are important. IPM is a challenging issue, which needs to look into new techniques, new management skills, and new concepts of integration to control insect pests of crops, protect the environment and provide continuous and abundant food supply. For this multidisciplinary research involving an integration of crop physiologists, entomologists, bio-meteorologists and biochemists becomes important. The success of any effort to develop IPM system is also based on maximising the impact of biological control agents, with industries cooperating to adopt reduced sales of broad spectrum insecticides, as well as market more selective compounds and formulations. It is because of the reluctance to change in this manner that IPM has suffered. The introduction of farmers' cooperation and active participation by agrochemical industry besides research organisations would help overcome this impasse.

The development of IPM programmes involves three phases viz., problem definition, research and implementation. The choice of control measures for IPM is essentially determined by two important aspects, the type of pest involved and socio-economic concern affecting the availability of various control products and techniques.

The definition phase requires a large number of inputs and should have a comprehensive approach based on a threshold framework to insect pest management, enabling integration of the various components formulated by different research groups. Integration can take place only when there is an appropriate institutional framework.

In the light of the above general aspects of IPM some examples would throw better light into the operational aspects. Taking the rice gall midge management, an IPM approach consisted of cultivation of resistant varieties, cultural practices like stubble destruction, early planting of susceptible varieties, judicious use of nitrogenous fertilizers and application of granules of phorate or carbofuran in nurseries. Select a pest resistant variety, adjust sowing/planting time in such a way as to avoid the crop's vulnerable stage with peak period of insect multiplication. Monitor the nurseries and apply insecticide only when the pest population is moderately heavy. Adopt cultural practices like optimum spacing, optimum nitrogen fertilizer application, sanitation of crop; monitor pest population or damage at seven to ten day intervals. Disperse or delay insecticidal use when the population of natural enemies is abundant.

In the case of other crops like sorghum, vegetables, etc. cultural practices and pest resistant cultivars should be exploited in IPM. Botanical insecticides such as Azadirachtin from neem (*Azadirachta indica*), *Vitex negundo*, *Pongamia glabra*, etc. should be exploited in pest control. Cropping system and cultivars that encourage natural enemies should be identified and fitted into pest management programmes. In the cotton ecosystem, the over and misuse of insecticides resulting in failure of control of the bollworms due to development of resistance to insecticides and resurgence of sucking pests are well known. Semiochemicals aiding in insect communication appear to be promising, since they tend to disrupt normal activity of insects. The pheromone Gossyplure effectively interferes with the mating of the cotton pink bollworm *Pectinophora gossypiella* and when it is applied alternately with selective insecticides yield of seed cotton increases. The IPM programmes implemented in cotton are such that they involve carefully selected methodologies, after taking into consideration the ecological aspects of the crop and its socio-economic impact.

The fact that biological control agents are competing with chemicals cannot be ignored and in the near future IPM will depend upon the availability of select chemicals to integrate with. The efficiency of traditional natural control can be enhanced by using biopesticides and pheromones. Castor is traditionally used in mixed crop plantations forming an active part of IPM.

Stacking genes or adding multiple types of toxin-coding genes to crops and replacing toxin-coding genes at regular intervals are all recent strategies in IPM. These are tested on the cotton bollworms with a view to build up greater stock of predators and parasitoids for better natural control. Control methods can be applied at various periods in the life cycle of the insect–mating, egg laying, larva, pupa and young and old adults. Through blocking the production of pheromones, release of sterilised males, interfering with neuropeptide function, etc. it is possible to prevent egg laying. Baculoviruses are ideal candidates in IPM because of their high degree of specificity and safety to beneficial parasitoids and predators and pollinators. Many of these baculoviruses cause epizootics and collapse of insect population, and spraying them in an early outbreak cycle accelerates collapse. Further, baculoviruses can be mixed with a variety of chemical pesticides including fungicides and insecticides as well as microbial agents such as Bt *(Bacillus thuringiensis)*. When larvae die from NPV (*Nuclear polyhedrosis virus*) or GV (Granulosis virus) infection, their bodies release large quantities of occlusion bodies on to the host plant resulting in horizontal transmission and a secondary cycle of infection.

Needless to emphasise that IPM is not an easy operational programme to achieve and what little is known does not involve all the aspects needed for a holistic approach. For instance, the necessity to understand the relation between weather, insect population dynamics damage to crops, yield loss and economic application of insecticides along with biocontrol agents or biopesticides is of paramount importance. If the interaction of natural enemies and the effect of agronomic practices or use of resistant cultivars are not included, then IPM becomes incomplete. All the same when all these aspects are included, the situation would be a complex one wherein it will be difficult to evaluate the role of each interaction. What is needed is the assembling and formulating of a conceptual model wherein the different components are identified with a better specification of their interrelationships.

◆ Chapter 80

Biological Control

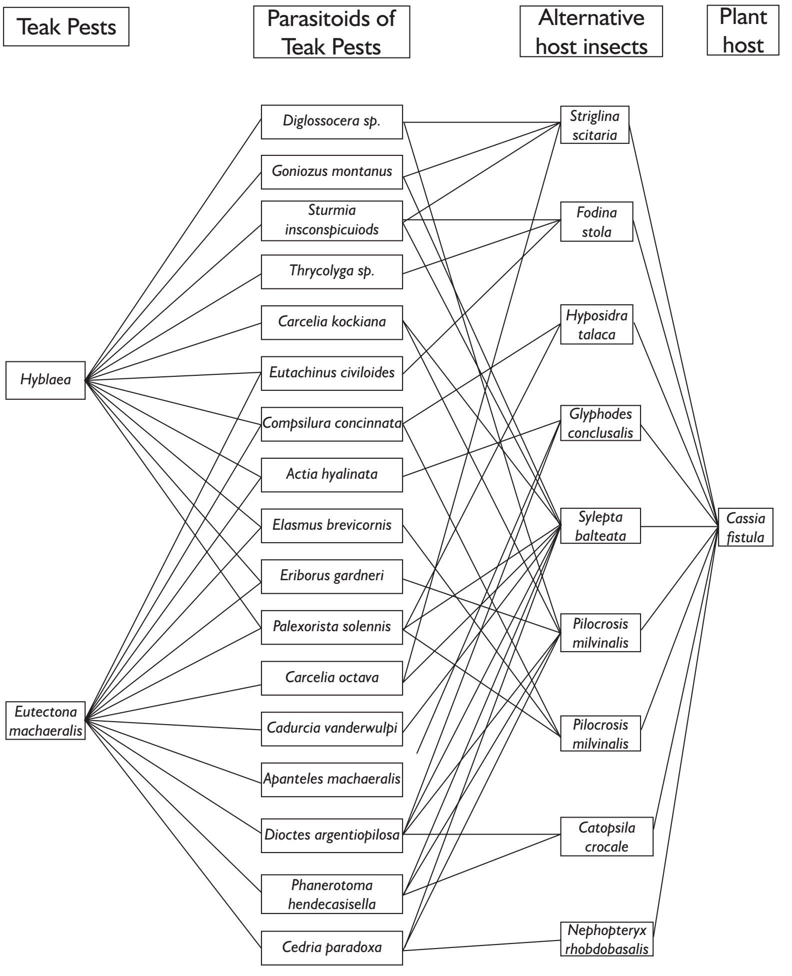
With the development of recent trends swinging towards population and population dynamics, studies on biological control methods have taken new dimensions and has, therefore, became a special field called "Applied Ecology," overlooking earlier attempts at defining it merely as the utilisation of parasitoids and predators in the control of insect pests. As defined in the context of our knowledge of population ecology, it is well known that in any population of insects there is a state of inherent stability in an ecosystem. Hence biological control is concerned with the environmental factors affecting the regulation and stabilisation of population of insects. The stability of populations in an ecosystem is termed "homeostasis." The most essential feature in biological control is the determination of the pest status of a species after a prior knowledge of the extent and the manner in which this homeostasis is disturbed. By colonising natural enemies available locally or by importing them from the countries of their origin, it is possible to ascertain how they disrupt the stability or position of equilibrium of the pest to a non-economic level and help in maintaining this level. By so regulating the pest populations, biological control plays an important part in insect control programmes. Ethology (behavioural aspects) is of importance in biological control studies in view of the data obtained regarding the behaviour of insects to their food source and hence in host selection. A correct knowledge of the centers of origin and distribution of the natural enemies as well as a proper taxonomic assessment are essential criteria in solving problems of biological control (Fig. 80.1).

The principal methods employed in biological control include:

(a) collecting parasitoids and predators from places of their origin and releasing them in places where they are absent;

(b) collecting and storing the host insects in such a way as to kill them, but permitting the parasites to escape;

(c) rearing under favourable conditions great numbers of parasites and predators and releasing them whenever needed; and importing parasitoids, predators or disease producing organisms from a foreign country.



▲ **Fig. 80.1** *Parasite complex of major teak defoliators to illustrate the variety of parasitoids and their alternate hosts (after K.S.S. Nair)*

The basic principles to be considered in the selection of a natural enemy are the similarity of natural conditions, which would help in the establishment of the natural enemy in the new environment; the degree of host specificity and genetic races of a given natural enemy may also play an important role in view of the possibly better bio-ecological adaptations of particular races. It is also essential to develop a genetic strain of the parasites superior to the wild stock to have better effects.

Parasitoids and predators, which are to be deployed for efficient biological control must have the ability to outnumber the host by their high reproductive rate, greater percentage of females, short life cycle; and ability to locate the host. They should also be able to withstand competition. The tendency to exihibit multiple parasitism of hosts and susceptibility to hyperparasites are undesirable qualities and reduce the efficiency of the parasites. Multiple parasitism is a type of parasitism in which the same individual insect is inhabited simultaneously by the young of two or more different species of parasites. Super parasitism has to be distinguished from multiple parasitism. Super parasitism is the parasitism of an individual host by more larvae of a single parasitic species, while multiple parasitism is a simultaneous parasitisation of a host by two or more different species of primary parasites. When a parasitoid super parasitises a host it usually condemns its own progeny or at least individuals of its own species to death. Although super parasitism results in a wastage of progeny, the resulting individuals become weakened and cannot stand intraspecific competition. Multiple parasitism on the other hand is considered a tragedy because even that parasite which wins over interspecific competition is tired, weak, dwarfed, shows low fecundity and becomes totally undesirable in biological control work.

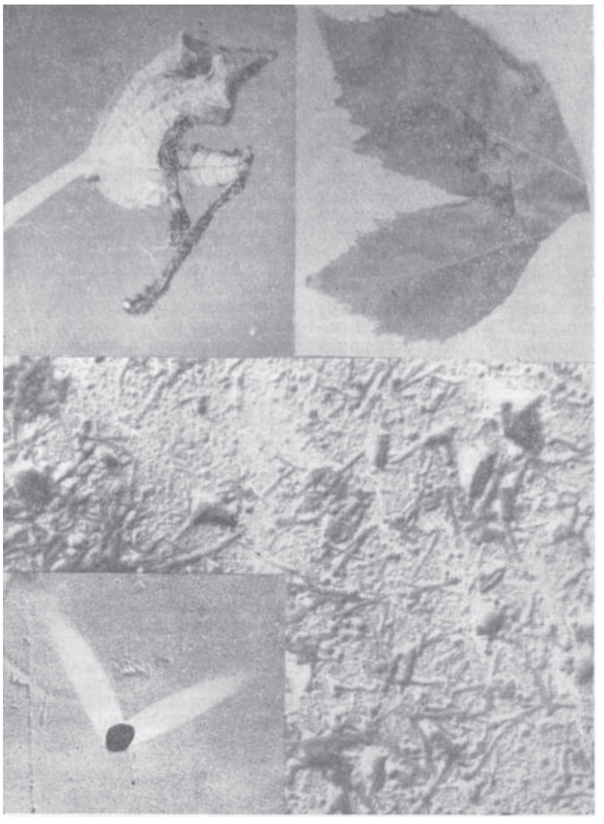
Very few primary parasites of any given insects are free from being parasitised by other parasites. The occurrence of higher parasitism in any (epi-parasitism) venture on biological control can only be considered as destructive, because a primary parasite imported for the purpose of introduction and establishment in the control of a pest may be overwhelmed by hyperparasites before it can succeed in controlling the pest.

Whether the host shows any defence reactions against the parasite should be an important consideration in any control programme. The most important is the problem of survival inside the body of another organism without arousing its immunological defence reactions. Normally the parasite is completely tolerated. The parasite develops and eventually destroys the host.

However, if the parasite lays its egg in an unnatural host, phagocytic haemocytes collect around the intruder in large numbers and encapsulate it. The parasite shrinks and turns black as melanin is deposited. Soon the parasite is sealed off and dies by asphyxiation. So encapsulation and melanisation are basic defence reactions against invading objects. Experiments have shown that repeated exposure of a host to the same parasite reduces their encapsulating ability. Again it was found that when a moth normally encapsulates 92 % of the singly laid eggs of an ichneumonid, and if super-parasitised by this species, the encapsulation rate drops to 3 %.

Another relatively recent aspect of biological control involves the application of insect's own pathogens for control. Like many animals, insects are also subject to many diseases—bacterial, fungal and viral. Many of these pathogens may be macerated or dried and distributed in water suspensions or as dry spores over large areas. *Bacillus thuringiensis* produces toxic protein crystals during spore formation. The active principle in the crystal is responsible for paralysis of the midgut within 5 to 20 minutes of imbibition of the sporulated bacillus, followed by paralysis of the body within one to seven hours. Lepidoptera and Coleoptera are most susceptible to this. Other bacteria are the deadly milky spore-producing bacteria *Bacillus lentimorbus* and *B. popillae*, which attack beetle grubs and caterpillars. Their action is to block the haemolymph and the whole blood becomes milky white. A new method for multiplying these spores in a liquid fermentation medium has been undertaken on an industrial scale. A talc-cum-limestone powder is chosen as the carrier of the commercially made milky dust. The dust is incorporated in the soil and the insects feeding on the roots consume the spores, get the infection and die.

Fungi were the first microorganisms recognised to produce diseases in insects, particularly the fungal diseases of silk worms produced by *Beauveria bassiana.* Subsequently, a more virulent fungus *Metarhizium anisopliae* was isolated from diseased grubs and even today used in the control of the coconut beetle. These fungal pathogens are known from all fungal groups Asco-, Basidio-, Phyco- and Deuteromycetes. Of the Phycomycetes, infections caused by Blastocladiales and Entomophthorales are very common. The Ascomycetes include a very common genus called *Cordyceps.* The Basidiomycetes are of little importance while the Fungi Imperfecti play a useful role in insect control. They infect their hosts not so much by ingestion but more by penetration through the integument, softening the hard chitin by releasing some enzymes. Once within the body cavity the fungus proliferates, invades all tissues and fills up the body cavity of the insect with thickly grown hyphae. Owing to heavy growth of the mycelium in the insect body, it becomes hard, stiff and mummified. Death is caused by the liberation of toxic substances—Mycotoxins. Death may also be caused by exhaustion or by mycosis or by paralysis or by asphyxiation through the plugging of tracheae.



▲ **Fig. 80.2** *Polyhedral virus of the tobacco caterpillar Spodoptera litura.Top left and right: The affected caterpillar; Bottom: The virus (courtesy : Dr. N. Ramakrishnan)*

About 250 virus infections have been recognised in about 175 insects. Of these, two are most outstanding, affecting most insects—the polyhedroses viruses (Fig. 80.2) and granuloses viruses. The polyhedroses viruses form polyhedra-shaped bodies containing the viruses in the infected tissues. Two types of polyhedra are recognised—the nuclear polyhedroses and cytoplasmic polyhedroses. The incubation period is 5 to 20 days and an infected larva stops feeding, becomes sluggish and dies. Shortly before and after the death, the integument becomes fragile and easily ruptures, emitting the liquified contents filled with disintegrating tissues and polyhedra. The granuloses viruses form small, granular, inclusion bodies called the capsules, each containing a virus particle. They are commonly used in the control of Lepidoptera and they attack the tracheae and blood cells.

The Sixth Commonwealth Entomological Conference held in London in 1954, recommended establishment of regional stations all over the world for work on biological control. Accordingly stations were started under Colombo Plan as a result of an agreement between the Governments of India and Canada and they were called Commonwealth Institutes of Biological Control. The Indian Station was started in 1957 at Bangalore. This station was taken over by the Indian Council of Agricultural Research and is presently known as the Project Directorate of Biological Control.

I. BIOLOGICAL CONTROL OF WEEDS

Biological control of weeds was started with the accidental introduction of the big *Orthezia insignis* which proved as a check against the proliferation of Lantana, an ornamental plant brought into Howaii. The weed, *Hypera perforatum*, a native of Europe, is known as St. John's Wort in Australia and New Zealand and as Klamath weed in the U.S.A. In California the weed was controlled by the introduced beetle, *Chrysomela gemellata*. Quite a few similar attempts on biological control of weeds in several countries have proved to be successful.

Insects should not be considered for noxious weed control, if they have been recorded as attacking plants of economic value. Insects recorded as attacking only the genus to which the noxious weed belongs or allies of it, having no economic value, should be subjects of future study.

1. Control of Cacti

One of the well known examples on the use of insects in the biological control of weeds was the fight against cacti in Australia. The prickly pear, *Opuntia inermis* got accidentally introduced into Australia by about 1840. The cactus spread so rapidly that in the course of next thirty years about twenty to twenty-four million hectares of arable land were rendered useless. The weed was attempted to be eradicated through the use of mechanical cutters, rollers and poisonous chemicals but without success. So, in 1925, the moth borer, *Cactoblastis cactorum* was introduced. The moth borer killed the plants by reducing them into papery structures.

The prickly pear *Opuntia vulgaris* Miller was suppressed in Central and North India by introduction of the mealy-bug *Dactylopius ceylonicus* (Green) from Brazil in 1795.

Experience of biological control of weeds in South India is another interesting story. The cactus *Opuntia dillenii* was wrongly introduced in 1780 in the place of *O. coccinellifera* for cultivation of the commercial cochineal insect *Dactylopius cacti* (L.), valued for its dye. The cactus got established. The cochineal insect was then obtained from Mexico. Since the insect was left with a wrong plant for its host, it did not thrive, allowing the cactus to spread rapidly and assume serious proportions as a noxious weed. Then the problem became one of eradication of the cactus. *Dactylopius opuntiae* Lichtenstein, a North American species, was introduced from Sri Lanka in 1926 and within two years the insect effected a striking control of *O. dillenii* and also of *O. elatior (O. nigricans)* to a lesser extent.

2. Control of Water-hyacinth *Eichhornia crassipes* (Pontederaceae)

Water-hyacinth is free-floating freshwater plant. It impedes flow of irrigation water, prevents free movement of boats; interferes with fishing and pisciculture, degrades the quality of water and increased silting and gradual drying of water bodies. It is also a threat to flooded rice fields where it reduces yield. In 1982 three exotic natural enemies viz. *Neochetina bruchi* Hustache, *N. eichhorniae* Warner (Curculionidae) and the mite *Orthogalumna terebrantis* Wallwork were introduced, and the former two have proved successful. *N. eichhorniae* adults are brownish-black and their body has grey and black scales. *N. bruchi* is reddish-black, broad-bodied, robust, densely clothed with agglutinate scales. Adults of both the weevils feed on the leaves of hyacinth and deposit their eggs below the epidermis of petioles and laminae. *N. bruchi* prefers basal ligules of outer leaves and *N. eichhorniae* prefers small, tender leaves. Whitish eggs of these species hatch in about a week.

The grubs are white or cream coloured with yellow or orange head. The grubs tunnel into the petioles and crown where they form pockets to feed extensively. The grubs leave characteristic black tunnels and the damage is often followed by invasion of pathogens, which weaken the plants further. Grubs pupate on live roots by cutting a lateral rootlet for making a spherical cocoon around themselves. Larval and pupal periods are completed in two months. The adults of *N. eichhorniae* and *N. bruchi* live for 142 and 134 days and lay 981 and 681 eggs, respectively. The weevil migrates up to 30 km.

These weevils can be used to control the weed. They can be reared in laboratories in large numbers under controlled conditions on the weeds and artificially inoculated on the weeds in natural conditions. Other management practices such as mechanical removal of the weed can also be followed simultaneously.

3. Control of Aquatic Weed *Salvinia molesta* (Salvinaceae)

This weed got introduced into India and first observed in the 1950s in Veli Lake in Thiruvananthapuram in Kerala. It became a serious weed since 1964. The weevil *Cyrtobagous salviniae* Calder and Sands, of Brazilian origin, was introduced from Australia in 1982 for the control of the aquatic fern *Salvinia molesta* and has now established in Kerala and Karnataka. Adults of the weevil feed on freshly emerged leaves and buds of *Salvinia*. They mate periodically throughout their life and the pre-oviposition period is 12.7 days with a range of 7.25 days. Adult males and females survive for up to 284 and 271 days respectively. Females oviposit up to 263rd day and a female lays 148 to 383 eggs. The eggs are laid mostly in the leaf keel and to a lesser extent in the root zone. Adults damage the leaf buds and the young terminal leaves; and feeding by larvae causes browning and decay of leaves. The capacity of the adults to live for as long as eight months combined with their ability to lay eggs continuously throughout their lives may be contributing to the effectiveness of the weevil.

The acridid grasshopper *Paulinia acuminata* (De Geer) introduced in 1974 got established but its potential as a bio-control agent has not been confirmed.

4. Control of Water-lettuce Pistia stratiotes L. (Araceae)

The water-lettuce has been noticed as a serious weed in Kerala. A noctuid caterpillar *Namagana pectinicoris* causes extensive damage to this weed and appears to be a potential bio-control agent.

5. Control of *Eupatorium adenophorum*

The exotic tephritid fly *Procecidochares utilis*, introduced from New Zealand in 1963 on *Eupatorium adenophorum* in the Nilgiris, caused galls on the plant but did not exercise effective control of the weed.

6. Control of *Chromalaena odorata* (Asgeraceae)

Chromalaena odorata, which is known as Siam weed, got introduced into Kolkata in the 1840s and has now spread throughout India. In Karnataka and Tamil Nadu it is a serious pest on plantation crops, forest areas, waste lands, and pastures. The leaf feeding moth *Pareuchaetes pseudoinsulata* Rego Barros (Arctiidae) was introduced in the 1980s in the Western Ghats. The seed feeding weevil *Apion brunneonigrum* (Apionidae) was also released in India but did not establish itself as a bio-control agent.

7. Control of *Parthenium hysterophorus* (Congress Weed)

The exotic beetle *Zygogramma bicolorata* Pallinter introduced from Mexico in 1983 for the control of the congress weed has been established in India.

8. Control of *Lantana camara* (Verbenaceae)

In the case of lantana, the introduced coccid, *Orthezia insignis*, in addition to its failure to effectively check the weed began to infest economic plants like citrus, coffee, cinchona and tomato; the seed fly *Ophiomyia lantanae* (Froggatt) introduced from Hawaii in 1921 did not establish itself in India. The Lantana bug *Telenomia scrupulosa* Stal. (Tingidae) was imported from Australia in 1941 and is suppressing the lantana weed successfully in some areas. In 1972 the chrysomelids *Octotoma scabripennis* Guerin Meneville and *Uroplata girardi* Pic. were introduced which got established.

II. BIOLOGICAL CONTROL OF INSECT PESTS IN INDIA

1. THE COTTONY CUSHION SCALE OR FLUTED SCALE *Icerya purchasi*

It is a scale insect, which is a polyphagous pest on a variety of fruit trees in Western countries. In Tamil Nadu it spread to an alarming degree on a variety of wild vegetation on the Nilgiris by about 1928. It had over 100 host plants but the only important crop affected was the wattle of commerical importance *Acacia decurrens.* The only successful way of controlling the pest is by its beetle predator *Rodolia cardinalis.* The beetles were initially got from California in May 1929, multiplied in the laboratory and released in infested areas. Another consignment of the beetles arrived from Egypt in 1930. By 1931, the incidence of the pest was practically reduced to negligible limits. A severe outbreak on Acacia was again reported from Kodaikanal in 1942 and subsequently from the Nilgiris also. Intensive work was taken up in May 1943 and continued till 1945. The activity later merged into an all-India coordinated scheme under the joint auspices of the then Madras Government (Tamil Nadu) and the Government of India.

Attempts made to introduce the exotic fly parasite *Cryptochaetum iceryae* against the pest were not successful. Similarly *Rodolia nezara* from Kerala, *R. amabilis* and *R. fumida* from Mysore and *R. breviscula* from Coorg were tried at Fernhill (Nilgiris) against the pest but did not succeed.

2. THE COCONUT BLACK-HEADED CATERPILLAR *Opisina arenosella*

It is one of the most serious pests of the coconut palm. The search for natural enemies and the attempts to employ them for biological control succeeded by 1926. Of the many natural enemies observed, the most important have been *Goniozus nephantidis* (Bethylidae) parasitising the grown-up caterpillars and *Trichospilus pupivora* (Eulophidae), a pupal parasitoid. These were bred in the laboratory and were released. To a lesser degree *Elasmus nephantidis* and *Bracon brevicornis* also proved to be amenable to mass breeding. These parasitoids are multiplied now in large numbers in the parasite breeding stations at several places in the country and liberated into the pest-infested areas for effective control.

An ichneumonid parasitoid *Eriborus trochanteratus* obtained from Sri Lanka was multiplied and released for the control of the pest around Coimbatore. The larval and pre-pupal parasitoids *Goniozus nephantidis, Bracon brevicornis, Apanteles taragamae* and *Elasmus nephantidis*, and the pupal parasitoids *Trichospilus pupivora*, *Tetrastichus israeli, Brachymeria nephantidis, B. lasus. B. nosatoi* and *Xanthopimpla punctata* are being mass multiplied in bio-control laboratories of Kerala for periodical releases.

(a) *Goniozus nephantidis* is shiny black in colour and ant-like in appearance. It is a larval parasite and attacks only *Opisina arenosella* caterpillars. The adults of the parasitoids, which emerge from the cocoons, are kept in 15 × 2.5 cm tubes. For feeding drops of sugar solution (1 part of sugar in 10 parts of water) are kept on a small paper slip dipped in wax; and the same changed every day. Mating takes place within a day or two of emergence. The mated females are separated and each parasite is taken in a small tube of 7.5 × 2.5 cm. Grown-up caterpillars are introduced into these tubes at the rate of one caterpillar per tube. The parasitoid paralyses the caterpillar and starts laying eggs. The elongate eggs are firmly glued on the sides of the host and 8 to 20 eggs are laid on a caterpillar. Grubs hatch in about 36 hours and begin to feed on the body fluid of their host. Larval stage lasts four to six days and pupal stage four days. When fully fed, the grubs detach themselves from the dead caterpillar and spin loose, flimsy cocoons of silk. The total life cycle varies from 11 to 16 days.

(b) *Trichospilus pupivora* is a tiny yellowish-brown wasp, which attacks the pupae of *Opisina.* In the laboratory it can be freely bred on pupae of various species of Lepidoptera such as *Ariadne merione merione, Conogethes punctiferalis, Plusia* sp., *Spodoptera litura*, *Syllepte derogata*, etc. Mating takes place inside the parasitised pupa even before emergence and hence the parasites are ready for egg-laying. Only fresh pupae of the host are taken in tubes of 7.5 × 2.5 cm and the parasites allowed inside at the rate of about 20 per tube. The minute eggs hatch in a day, and the grubs become full grown in five to six days and form naked pupae. The pupal period is about 16 to 17 days on an average. It cannot survive the summer conditions and has to be propagated every year.

The parasitoids are taken to the top of the trees and released at the rate of about 10 parasitoids per tree in a few places in a garden.

(c) *Spoggossia bezziana*, the exotic tachinid fly parasitoid, from the then Commonwealth Institute of Biological Control, Bangalore, was mass multiplied and liberated into the coconut gardens (Fig. 80.3) around Coimbatore. The attempts were not continued.

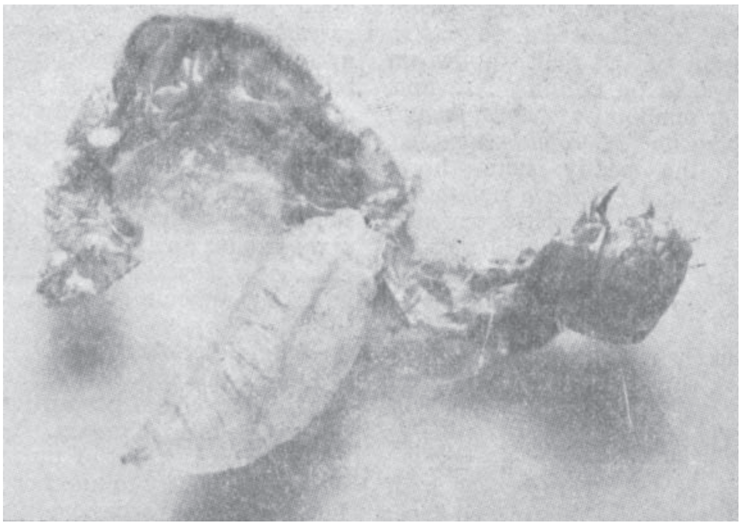


Fig. 80.3 *The tachinid Spoggossia bezziana emerging from the caterpillar of Opisina arenosella (Courtesy: Dr. V. P. Rao)*

3. SUGARCANE BORER *Chilo infuscatellus*

The eggs of *Corcyra cephalonica* are collected and they are used for multiplication of the parasitoid. For this purpose the moths collected are put inside an inverted big-sized funnel having its bottom closed with a wire-mesh. This funnel is kept on a piece of white cardboard overnight. On the next day morning the eggs deposited on the cardboard are collected. The eggs are sprinkled on a wet paper and then dried. These cards are kept inside a tube and the *Trichogramma chilonis* parasitoids are introduced. In two to three days the eggs get parasitised and the parasitised eggs turn dark. The parasitised egg cards are sent to the respective places for hanging them in the sugarcane fields. The parasites come out of the eggs and attack the eggs of *Chilo infuscatellus*. Stapling 100 egg-cards (5×2.5 cm) with seven-day old eggs of *Corcyra* parasitised by *T. chilonis* to the undersides of leaves of sugarcane from July to October at 10-day interval is suggested. Normally 10 to 12 releases at the rate of 50,000 parasitised eggs/ha is recommended.

4. THE INTERNODE BORER *Chilo sacchariphagus indicus*

Inundative release of *Trichogramma chilonis* at 2,50,000 parasitoids/ha in phases during the different stages of crop growth i.e. 25000 parasitoids/ha per release during fourth and ninth months and 50,000 parasitoids/ha per release during fifth, sixth, seventh and eighth months is recommended for the control of internode borer in Tamil Nadu.

5. THE TOP BORER OF SUGARCANE *Scirpophaga excerptalis*

The ichneumonid parasitoid *Gambroides javensis* has been found promising in the control of the top borer on sugarcane in Pugalur area. Inoculative release of the parasitoid at the rate of 125 females/ha in fields showing more than 10% top borer infestation is recommended.

6. THE STALK BORER *Chilo auricilius*

The cuban fly *Lixophaga diatreae* imported from Taiwan in 1962 indicated promising results in the control of the stalk borer *Chilo auricilius.* It has been found that in Uttar Pradesh, the fly has been able to survive the North Indian winter. Another fly *Diatraeophaga striatalis* (tachinid) received from Malagasy Republic in 1965 was released in Tamil Nadu. Sequential release of 125 gravid females of the tachinid parasitoid *Sturmiopsis inferens* per ha from 30^{th} to 50^{th} day of planting is suggested.

7. THE SUGARCANE SCALE *Melanaspis glomerata*

Release of about 1500 beetles of *Pharoscymnus horni* or *Chilocorus nigritus* per hectare at the first appearance of the scale insect is suggested. *Sticholotis madagassa* Weise (Coccinellidae) and *Anabrolepis mayurai* Subba Rao have been found suitable for suppression of the scale.

8. THE SUGARCANE PYRILLA *Pyrilla perpusilla*

Effective nymphal and adult parasitoid *Epiricania melanoleuca* has also been successfully colonised in Gujarat, Madhya Pradesh, Maharashtra, Rajasthan, Karnataka and West Bengal besides other areas in the control of sugaracane pyrilla. Release of 8,000 to 10,000 cocoons or 8,00,000 to 10,00,000 eggs of *E. leuconella* per ha is recommended. Leaf bits bearing two to three egg masses or five to seven cocoons can be stapled to the underside of sugarcane leaf at several places in the field.

9. THE APPLE WOOLLY APHIS *Eriosoma lanigera*.

This is a serious pest of the apples and the recognised method of control is by systematic colonisation of its specific parasite *Aphelinus mali.* Consignments of the parasite were obtained from Punjab in 1940 and liberated in the Pomological Station, Coonoor. The work was intensified from 1944 onwards and appreciable control has been effected. Heavy predation by *Coccinella septempunctata* and *Adonia variegata* also keeps the pest under control.

10. THE APPLE SAN JOSE SCALE *Quadraspidiotus perniciosus*

Russian, American and Chinese strains of *Encarsia perniciosi, Aphytis diaspidis* and *A. proclia* group effectively suppressed this pest on apple. *Chilocorus bijugas, Pharoscymnus flexibilis* and *Cybocephalus* sp. also play an important role in the population suppression of this pest.

11. THE APPLE CODLING MOTH *Cydia pomonella*

Inundative releases of *Trichogramma cocoeciae* and *T. embryophagum* have been found promising against apple codling moth in Ladakh.

12. COTTON BOLLWORMS

Weekly releases of *Trichogramma* at 25,000 per hectare from flowering season till the ripening of the bolls showed a progressive decline in infestation of the bollworm *Helicoverpa armigera* and pink bollworm *Pectinophora gossypiella* on cotton. The exotic parasitoid *Bracon kirckpatricki* has suppressed the cotton bollworms in Karnataka, Haryana, Punjab and Gujarat. It was also found parasitising hibernating larvae of pink bollworm in the north. *Chelonus blackburni* has established in north as well as in the south. Utilising the parasitoids *Trichogramma brasiliensis, T. chilonis, C. blackburni* and *B. kirckpatricki*, the predator *Chrysopa scelestes* and the NPV of *Helicoverpa armigera* the cotton bollworm complex can be effectively suppressed.

13. THE RICE STEM BORER *Scirpophaga incertulas*

The rice stem borer incidence is reduced by periodical release of the parasitoid *Trichogramma chilonis* at 40,000-50,000 parasitoids/ha.

14. THE RICE LEAF FOLDER *Cnaphalocrocis medinalis*

Periodical release of *Trichogramma australicum* at 50,000 parasitoids/ha has given effective control.

15. THE BROWN PLANTHOPPER (BPH) *Nilaparvata lugens*

Release of the mirid bug *Cyrtorhinus lividipennis* at 100 bugs or 50-75 egggs/m^2 at 10 days interval checked the build up of BPH population to some extent.

16. THE TOBACCO CATERPILLAR *Spodoptera litura*

Since 1974 the egg parasitoid *Telenomus remus* (Scelionidae), obtained through the Commonwealth Institute of Biological Control, Bangalore, was mass multiplied and released in Rajahmundry (Andhra Pradesh) for the control of the tobacco caterpillar.

17. THE CITRUS BLACKFLY (CBF) *Aleurocanthus nagpurensis*

There was an outbreak of the CBF in the Vidarbha region of Maharashtra state and the species was established as *Aleurocanthus nagpurensis*, though earlier it was variously identified as *A. woglumi* and *A. husaini*. This species has been effectively kept under check by the parasitoid *Encarsia orangae*. The methods for mass rearing of the pest and the parasitoid were developed at Nagpur University and releases made during 1986 and 1987 in the citrus orchards at Nagpur University brought the pest under check by 85-90% within one year. This appears to be a potential bio-control agent for the control of *A. nagpurensis.*

18. THE SUBABUL PSYLLID *Heteropsylla cubana*

The exotic coccinellid *Curinus coerulens*, a shiny bluish-black beetle was introduced into India from Thailand in October 1988 for the control of the psyllid, which got entry into India in February 1988.

19. THE AUSTRALIAN LADYBIRD BEETLE *Cryptolaemus montrouzieri* (Coccinellidae)

This was imported into India in 1898 from the USA. Since then it was seen occurring in Taliparamba in 1930, in Bangalore in 1940 on mealy bugs and in 1951 on trunks of Araucaria pines, in Anamalai in 1931 on guava scale and in Coimbatore in 1942 on guava scale and in 1944 on brinjal. During the survey of the Cactus on the Nilgiris it was found at Anikorai that the cochineal *Dactylopius tomentosus* on the prickly pear *(Opuntia dillenii)* was being preyed upon by the adults and larvae of this beetle. Experiments conducted on the mass multiplication and releasing of the predator at Coimbatore for controlling mealy-bugs like *Coccidohystrix insolitus* on brinjal, *Chloropulvinaria psidii* on sapota and guava, *Pseudococcus corymbatus* on citrus, *Pulvinaria maxima* on neem, etc. gave some control. However, the relief was only partial due to depredatory activity of the ants, which proved inimical to the predatory grubs and adults. It has also to be replenished every year. Presently it is used for the control of mealy-bug on grapevine.

The other common predaceous insects in South India include, the coccinellid beetles *Cheilomenes sexmaculatus* on aphids on a variety of crops and *Chilocorus nigritus* predominantly on scale insects attacking coconut, betelvine, neem, tapioca, etc.

BIOLOGICAL CONTROL THROUGH PREDATORY VERTEBRATES

Among the vertebrates, the birds are in fact the most effective bio-control agents as a proportion of food of most birds is made up of insects. Yet, there have been no spectacular cases of transportation of birds from one country to another to combat insects. In South India, occasionally ducks are allowed into paddy fields for feeding on the striped bug Tetroda histeroides. A flock of 1000 ducks can clear a badly infested patch of about 5 ha in the course of two or three days, each bird accounting for about 500 bugs in a day. However, some birds play the role of bio-control agents of insect pests of different kinds such as caterpillars, grasshoppers, white grubs, etc. The important insectivorous bird species are: the mynah *(Acridotheres tristis)*, the king crow *(Dicrurus ater)*, the wood pecker *(Brachypternus auranticus)*, the owl *(Athene brama)*, the house crow *(Corvus splendens)*, the common weaver bird *(Ploceus phillipinus)*, the house sparrow *(Passer domesticus)*, the common bee eater *(Merops orientalis)*, the rose-ringed parakeet *(Psittacula krameri)*, the black rock pigeon *(Columba livio)*, the bulbul, the tailor bird, the hoopoes, the fly catcher, fowls, turkeys, etc.

BIOLOGICAL CONTROL THROUGH NEMATODES

Nematodes especially rhabditids are found to have a symbiotic relationship with the bacteria, forming a disease complex. The best known disease complex was discovered by Dutky and Hough in 1955 in the caterpillars of the codling moth, *Cydia pomonella* (L.). The complex was known as DD-136 though the nematode itself was often called so. The nematode involved is *Steinernema feltiae* (*Neoaplectana carpocapsae* Weiser) and the bacterium *Xenorhabdus nematophilus.* The nematode serves as a vector for the bacterium, which produces speticemia in the insect body. When the nematode enters the insect body the bacteria are released and they multiply. The nematode ingests both the dead host tissue and the bacteria. The bacteria are retained in nematode intestine, as the latter does not feed during its free-living existence. When such bacteria-carrying nematodes invade fresh insect hosts they are killed likewise. Though even a few nematodes can kill the host, sufficient number of them should invade the host to ensure reproduction through production of each sex of nematode. The dead body of the insect remains intact with putrefaction for more than three weeks, perhaps due to production of certain antibiotic by bacteria that inhibits the growth of other micro-organisms. Both nematode and bacteria can be cultured separately. A wide range of insect species is susceptible to the disease complex. In India it was tested against rice and sugarcane borers and codling moth. It was found promising against larvae of *Helicoverpa armigera.*

The mermithid *Ovomermis albicans* is parasitic on larvae of *H. armigera* and *Spodoptera litura* and need to be evaluated.

BIOLOGICAL CONTROL THROUGH INSECT DISEASES

Employment of micro-organisms capable of causing diseases in insects is another means of fighting crop pests, i.e. number of fungi, bacteria, viruses and protozoa are able to cause diseases in insects.

(a) Bacteria

Dutky in 1937 found an oval-shaped bacterium containing spindle shaped retractile bodies associated with a species of *Neoaplectana* occurring in the larvae of Japanese beetle *Popillia japonica* Newman. He showed that the bacteria could be transferred by the nematodes from one larva to another. The control of this beetle by the nematode-transmitted bacterium *Bacillus popillae* provided an outstanding example of practical utilisation of an insect disease in the control of insects.

Out of about 100, pathogenic bacteria described from insect *Bacillus thuringiensis* Berliner has been found to be the most useful one. It was isolated by Berliner in 1915 in Germany from the diseased larvae of the Mediterranean flour moth, *Ephestia kuhniella.* It is a spore-forming crystalliferous bacterium. Since 1946 it has been tried in insect control and has been found to b capable of killing many lepidopterous larvae. The infection occurs through ingestion and the bacterium develops in the intestinal tract of its host later passing on to it haemocoel causing septicemia. *Bacillus thuringiensis* and related genera are highly pathogenic to those lepidopterous larvae, which have an alkaline pH of the gut but are non-pathogenic to those having slightly alkaline or neutral gut pH as in the larva of noctuids and sawflies. In this respect action of *B. thuringiensis* toxin is very much similar to that of the phytogenous insecticide, rotenone, for ingestion of small quantities of rotenone can bring about rapid death in silk worm larvae with a high gut pH whereas even large quantities will not have any adverse effect and the ingested rotenone is voided in faeces in *Spodoptera* catepillars with a low gut pH. In susceptible insects the crystalline toxin of the bacterium makes the gut wall permeable to spores and bacteria and as a result the latter pass into the haemocoel and cause septicemia. In infected insects the blood pH is usually lowered. But in most susceptible insects, which have a highly alkaline gut contents, because the gut wall is made highly permeable by the toxin, the alkaline fluids in the gut permeate into the haemocoel resulting in an increase in blood pH. In several countries like U.S.A., France, Germany, Czechoslovakia and U.S.S.R. this bacterium is produced in large quantities and its commercial preparations are marketed. Since the main activity of *B. thuringiensis* against insects is a result of toxins, which act as stomach poison, the bacterium has to be applied regularly and in correct quantities as in the case of chemical insecticides without depending upon its natural spread. The bacterial spore dust is prepared by growing bacteria over large areas of nutrient agar. The bacterial spores are washed off with a little quantity of water, added on to one of the usual dust carriers of chemical insecticides especially the talc, dried in an oven and pulverised to a fine powder. The formulation is so standardised that a gram of concentrated spore-dust suspension has 100 million spores. It can be applied as a dust or water suspension spray against a variety of lepidopterous and coleopterous larvae. It is non-toxic to man, other vertebrates and beneficial insects. It leaves no residue in plants. It is compatible with a number of chemical insecticides like carbaryl, demeton, malathion and parathion. The microbial insecticide is to be applied under proper weather conditions, especially temperature and it lacks residual action.

Another bacterium of recent application in biological control of insects is the red pigmented bacterium, *Serratia marcescens* Bizio. It belongs to a non-spore-forming type and has been found to be useful against a number of lepidopterous insects. The bacterium *Coccobacillus acridiorum* has been used against grasshoppers in part of Africa.

Bacteria based Biopesticides in India

1. Agricultural Pests Control

Bacillus thuringiensis var. *kurstaki* is available as a water dispersible powder formulation. It is selectively toxic to the lepidopterous larvae of various crops and has no harmful effect on human, warm blooded animals, wild life like birds, fishes frogs, honey bees and other beneficial insects. The product is based on a highly potent strain of *B. t. var. kurstaki*, serotype H 3a, 3b isolated in 1962. It is toxic to caterpillars such as *Helicoverpa, Plutella, Spodoptera, Earias, Spilarctia, Amsacta, Agrotis, Lymantria,* etc. Viable spore count in the commercial formulation is around 90-102 billion spores/g. Early instar larvae are most susceptible and later instars show little effect due to cessation of feeding by caterpillars. It exhibits quick knockdown activity within few hours of application and kills within two to three days of application. It is recommended at 0.5 to 1.0 kg/ha. This product has been registered for use in India and is now being produced, formulated and marketed.

Bacillus popillae occurs naturally in India and when applied as spores, has been found effective under field conditions against the white grubs *Holotrichia consanguinea*, *H. serrata* and *Leucopholis lepidophora.*

2. Public Health Pests Control

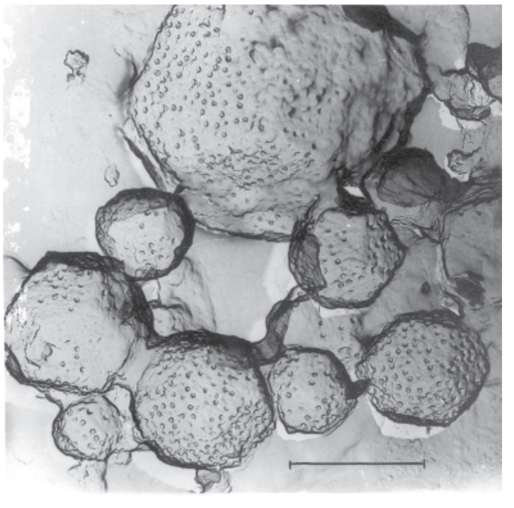
Bacillus thuringiens is var. *israelensis*, Serotype H-14, strain 164, is available as a water dispersible powder formulation. It is highly effective against first three larval instars of various mosquito species of the genera *Aedes, Culex, Anopheles, Mansonia,* etc., which are vectors of malaria, filarial, encephalitis and dengue fever in addition to being of nuisance. It is applied at 1.0-5.0 kg/ha, at 0.5 g/sq. m. water surface, as 0.5% suspension, by knapsack sprayer at two to six weekly intervals. It results in sharp and continuous decline of *Anopheles* and *Culex* larval populations (90-97%) in various habitats and different ecological sites including drains, water streams, sewage tanks, water coolers, cooling towers, fountains, construction sites, rice fields, septic tanks, ditches, pools, marshy ponds, etc. It is used by NMEP (National Malaria Eradication Programme), Municipal Corporations in Delhi, West Bengal, Maharashtra, Tamil Nadu and Kerala, and also by World Health Organisation (WHO) in Maldives. This product has been registered for use in India.

Bacillus sphaericus has also been found to be effective against the larvae of the mosquitoes mentioned above.

(b) Viruses

More than 250 insect viruses have been described as capable of causing diseases in insects. The jaundice or *grasseri* of silkworm, paralysis of honey bees and polyhedrosis of caterpillars are some examples of viral diseases in insects. Infection in insects by certain viruses is distinguishable by the presence of characteristic cell inclusions and that by certain others by the absence of any inclusions. The inclusion may be polyhedral, polymorphic, or granular.

The polyhedrosis virus may be called as nuclear or cytoplasmic, according to the site of its multiplication. The nuclear polyhedral virus, Borrelinavirus, is rod shaped and multiplies in body wall tracheae, fat bodies and blood cells. The polyhedra are seen in nuclei of cells. The cytoplasmic polyhedral viruses multiply in cell cytoplasm of the gut and the polyhedra are never seen in cell nuclei. In the case of nuclear polyhedrosis viruses, they invade the cells and multiply and the multiplied viruses invade uninfected cells. Polyhedra are formed in the cell nuclei. The polyhedra and the host nuclei enlarge in size and the infected cells are ultimately destroyed releasing the polyhedra into the body cavity. A few hours after the larvae die of polyhedral diseases, their internal tissues become liquefied, containing large number of polyhedral bodies in the liquid. An individual polyhedra is about 0.5 to 15 microns in diameter, never sphere-like and is usually refractive and crystal-like with many faces; it is made of concentric layers like an onion. Nuclear polyhedrosis viruses have been observed to affect about 200 species of insects, mostly of Lepidoptera and to a less extent of Hymenoptera and Diptera. The viruses are carried from one generation to the next, through transovum infection. In India nuclear polyhedroses of *Corcyra cephalonica, Pericallia ricini, Amsacta albistriga, Spodoptera litura* and *Helicoverpa armigera*, cytoplasmic polyhedrosis of *Helicoverpa armigera* (Fig. 80.4) granuloses of *Pericallia ricini, Chilo infuscatellus* and *Cnaphalocrocis medi-nalis* have been observed. Insect viruses have the greatest potential for field use because of their specificity and effectiveness against



▲ **Fig. 80.4** *Electron micrograph of carbon replicas of cytoplasmic polyhedra of Helicoverpa armigera showing pits where virions have been etched. Line = 1.01 μ (Courtesy: Dr. R.J. Rabindra)* many important crop pests. The nuclear polyhedroses and granuloses are most lethal and also the most promising viral insecticides. Though non-inclusion viruses also quite virulent, their environmental presistence is questionable. Polyhedroses of *Chilo, Carpocapsa, Estigmene, Helicoverpa, Laphygma, Pieris, Plusia, Spodoptera and Trichoplusia* are some of the commercial viral insecticides available in other countries.

Baculoviruses in Pest Control in India

The baculovirus group of viruses is the most predominant among the insect viruses and is apparently confined to invertebrates particularly the insect orders Lepidoptera, Hymenoptera, Diptera and Coleoptera. These viruses are structurally complex with double stranded DNA having rod-shaped or bacilli-form virions. In the majority of the cases virions are occluded within a crystalline protein coat to make up a virus inclusion body. These inclusion bodies are polyhedral in shape in the case of nuclear polyhedrosis viruses (NPVs) or form capsules as in case of granulosis viruses (GVs). No inclusion bodies are formed in some baculoviruses such as *Oryctes* virus wherein nucleocapsid is always enveloped singly within the virion. In India among 35 insect viruses recorded, the most important are the NPVs of *Helicoverpa armigera, Spodoptera litura, Spilarctia obliqua, Achaea janata* and *Amsacta albistriga* and GVs of *A. janata, S. litura, H. armigera, and Chilo infuscatellus.* The granulosis virus infecting sugarcane shoot borer is found widely distributed in Tamil Nadu and Pondicherry. Four sprays of the virus at $10^{-6} - 10^{-8}$ inclusion bodies/ml applied at fortnightly interval commencing from the 30th day of crop stage have given good control of the pest. However, large scale production of the virus is rather difficult in the absence of an alternative host and there are also limitations in mass rearing of the shoot borer.

A number of companies, Agricultural Universities and state departments of agriculture produce NPVs of *H. armigera, S. litura* and *Amsacta albistriga* and supply them commercially to the farmers for pest control. The product Biovirus marketed in India is a moisture absorbing powder formulation of *H. armigera* NPV containing 7×10^{-9} PIB/g having a storage stability for two years at 40°C. It is applied at 300-500 g/ha, two to three times at 10-15 day interval.

Baculovirus oryctos has been found to successfully control the coconut beetle *Oryctes rhinoceros* under field conditions in the Lakadive Islands.

(c) Fungi

Out of about 530 entomopathogenic fungi described under all classes, viz, Phycomycetes, Ascomycetes, Basidiomycetes and Deuteromycetes, about fifty species of the genera *Entomophthora* (Phycomycetes), *Aspergillus, Beauveria, Isaria, Metarhizium* and *Spicaria*

(Deuteromycetes) are more commonly found in insects. They attack usually dipteran insects followed by Hemiptera, Lepidoptera and Coleoptera. In all cases the adults are more commonly affected than the larvae. *Entomophthora grylli* on grasshoppers, *E. sphaerosperma* on cabbage butterfly and leaf hoppers, and *Metarhizium anisopliae* on sugarcane pyrilla and grubs of rhinoceros beetle are some common examples of fungal diseases in insects. In South India, *Cephalosporium lecanii, Entomophthora lecanii* and *E. fresnii* have been noticed to keep in check the coffee green scale *Coccus viridis. Spicaria* sp.and *Cladosporium* sp. on the castor whitefly *Trialeurodes ricini, Aspergillus flavus,* on *Pelopidas mathias mathias* and *Henosepilachna vigintioctopunctata*, and *Cladosporium* sp. on *Icerya purchasi* in the Nilgiris are other fungi noticed. *Beauveria bassiana* infects castor semilooper and *Isaria stellata* infects *Amritodus atkinsoni* and *Idioscopus clypealis* in Mysore.

Beauveria brongniartii is the most abundant white grub pathogen and infects members of Rutelinae, Melolonthinae, and Cetoniinae and deserves consideration. *B. bassiana* infects *Holotrichia serrata. Paecilomyces farinosa* infects *Eligma narcissus. P. fumasoroseus* naturally infects adults of the whitefly *Bemisia tabaci.*

Most of the entomopathogenic fungi are facultative parasites. The infective spore on germination penetrates the integument with mechanical pressure or enzymatic action. Hyphae can also initiate infection. They produce toxins, which act as poisons for the insects. The toxins produced by *B. bassiana* are Beauvericin, Beauverolides and Bassinolide and by *Metarhizium* are Destruxins A,B,C.D,E,F.

The fungi that are commercially produced and used in the biological control of insects are *Beauveria bassiana* and *Metarhizium anisopliae* by small scale units in the country.

(d) Protozoa

The result of parasitism by protozoa on insects is mainly debilitative, predisposing them to death by other causes. About 210 pathogenic protozoa have been described in insects. They include such well-known species as *Nosema bombycis* on silkworms, *Malpighamoeba mellificae* on honey bees in Europe and *M. locustae* on grasshoppers. The protozoan *Farinocystis tribolii* has been noticed to infect *Tribolium castaneum* in India. The role of protozoa as microbial agents in artificial control is limited because of the difficulties in their mass production for field release. The various protozoan pathogens propagated in other countries for use in biological control include *Malamoeba locustae, Mattesia grandis, Nosema bombycis, N. lymantriae* and *Perezia pyraustae. P. pyraustae* has been used against the European corn borer.

BIOLOGICAL CONTROL OF VECTORS AFFECTING MAN

(i) *Domiciliary Cockroaches* In India augmentative releases of the indigenous parasitoid *Tetrastichus hagenowii* (Ratz.) (Eulophidae) have given promising results in the control of

Periplaneta americana. The cockroach *Neostylopyga rhombifolia* (Stoll.), restricted to thatched huts, is parasitised by *Anastatus umae* Boucek (Eupelmidae). *Evania appendigaster* (L.) (Evaniidae) is parasitic in the oothecae of *Periplaneta americana, P. brunnea* Burmeister, *P. australasiae* (F.) and *N. rhombifolia*, but is only of minor importance.

(ii) *Housefly* Five species of parasitoids viz., *Spalangia cameroni* (Perkins), *S. endius* Walker, *S. nigra* Latreille, *S. nigroaenea* Curtis and *Pachycrepoideus vindemmiae* Rondani (Pteroma-lidae) are parasitic on puparia in pig manure. In addition, *Dirhinus pachycerus* Masi (Chalicididae) parasitises the puparia in poultry manure. *S. cameroni, S. endius* and *S. nigroaenea* pararistise the puparia in cattle manure.

(iii) *Mosquitoes* Three species of exotic larvivorous fish *Carassius auratus* (L.), *Gambusia affinis* (Baird and Girard) and *Poecilia reticulata* Peters have been successfully colonised in many parts of India to destroy mosquito larvae in wells, ponds and other confined water bodies.

ADVANTAGES OF BIOLOGICAL CONTROL

1. The control over the insect is exercised in a wide area. The co-operative effort of the farmers of a locality is not necessary, as will be required in large scale chemical control operations like aerial spraying.
2. Though the initial cost in procuring the biological agents and initiating the project may be high, in the long run it becomes cheaper as the recurring expenditure will be very little later on.
3. The pest is hunted out even in its wild haunts inaccessible for other methods of control and thus a complete control over a large area is possible.
4. The biological agent will survive as long as the pest is prevalent and, therefore, the control effected may last over a long period.
5. When successfully established the biological agent can perpetuate itself and, therefore, after a few years of field release there may not be any necessity to propagate it further.

Limitations of Biological Control

1. It is a slow process and takes a long time. An imported natural enemy, if it does not establish itself within three years of careful release under optimum conditions, may not be an useful biological agent Further, the farmer does not like to wait for the natural enemy to do its job and he always expects quick results of control.

2. The work of the natural enemy cannot be restricted to particular crops or areas.
3. If alternative hosts of the natural enemy are present in abundance, the control exercised over a specific pest may not be to the desired extent.
4. If certain seasons of a year are unfavourable for the normal development of a natural enemy, replenishment will become necessary every year.
5. The effect and progress of the work of the natural enemy will be affected considerably if it is attacked by hyper parasites in the locality.
6. Use of chemical pesticides adversely affects the population level of natural enemies.

◆ Chapter 81

Insect-Plant Interactions

The adaptive spectrum of insects to their host plants involves behavioural as well as metabolic changes, which reflect the overwhelming diversity in insect-plant interactions. These changes enable insects to cope with the physical and chemical defence systems in plants to which phytophagous insects have long been adapted during evolution. Detoxification and chemosensory mechanisms enable these insects to respond differently to different chemical compounds so that they are able to identify the plants to which they are chemically adapted. For purposes of defence, plants have been known to extend a portion of their metabolic energy and nutrients on various host selection devices. This process of co-evolution or reciprocal adaptation has come to be recognised, although the pattern of feeding diversity eludes convincing explanation. Phytophagous insects derive adequate nourishment from most plant tissues, and different species have different nutritional requirements, so that varying degrees of feeding discrimination are evident. The degree to which a plant species is immune to the attack of insects in general, is indicative of the defence strategies it has evolved, as well as the evolved abilities of insects to overcome the defences. While this is what has been termed 'the evolutionary arms race', there has been an increasing trend to consider insect-plant interactions as involving an integration of numerous complex chemical and non-chemical factors. In other words insect-plant interaction can be better understood only when approached as a holistic phenomenon in community ecology. For instance, the adaptive flexibility of insects to respond to ecological selection pressures is as important as the chemical composition of food plants. A knowledge of plant chemistry will ultimately make it possible to better understand insect community structures because of its influence on population, energy flow, and nutrient cycles. Issues such as the role of water, nitrogen, and phenolics in insect feeding, physico-chemical and biophysical aspects of interaction of natural toxins enable an understanding of the sequestration and detoxification mechanisms as well as mechanisms of plant resistance; these have to be examined in depth in relation to the feeding and reproductive processes in insects. The physiology and behaviour of as many phytophagous insects as possible need to be studied in order to provide a more convincing picture of the spectrum of interaction involved, since the presence of specific chemicals may offer protection from one insect pest, but may increase risk of invasion by others.

WATER AND NITROGEN

The role of water as a stimulus in eliciting an orientational response of phytophagous insects towards the host plant has often been overlooked. Insects such as the leaf miners and gall insects are protected from desiccation by their habitats and rapidly die from loss of water when removed from their immediate surroundings. In the absence of plant odour the stimulus provided by a thin layer of moist air associated with leaf surface could evoke a positive response.

Several problems have emerged in recent years regarding the leaf surface, from surface trichomes to cuticular lipids. The role of cuticular lipids in insect-water balance and reaction to water stress appears to be related to the lipid composition of the host plant. The increasing realisation that the regulation of water in insects involves an inter-disciplinary approach embracing biophysics, ecology and cell physiology, has opened up new areas of useful research. Regulation of water balance is also one of the ways to successfully adapt phytophagous insects to a wide range of habitats.

Plants are also known to defend themselves through lower levels of nitrogen, or low water/nitrogen ratio, and several plants are known to store nitrogen as non-protein amino acids so that there is a combined operation of reduction in available nitrogen with chemical defences. Increased plant nitrogen increases insect damage and plants generally exhibit seasonal patterns in the levels of nitrogen in leaves, fruits, stems and various tissues. The survival and reproduction of insects are influenced by both the quality and quantity of nitrogen. In addition, the ability of insects to ingest, digest and convert plant nitrogen is also important, besides the utilisation of amino acids. While insects have high protein content, plants contain predominantly carbohydrates and thus nitrogen content in protein is often a critical component for insects.

Water influences insect growth in the immature stages. Foliage water content varies with plant growth form. Young leaves and shoots contain a high percentage of water compared to the mature parts. Thus the age of a leaf and consequent availability of various chemicals play a vital role in host selection. Obtaining an adequate intake of protein and amino acids becomes more complicated due to variation in leaf nitrogen content as well as water content in relation to seasonal changes.

PHYSICAL AND CHEMICAL DEFENCE SYSTEMS IN PLANTS

Many phytophagous insects have developed trophic strategies to exploit plant structures or orientation mechanisms so that the average size of the species guild is an indicator of the adaptive radiation, which may occur on the same plant species, where different regions are exploited by very closely related species. As related plant species usually offer similarities with regard to structural features and chemical compounds, such species require less utilisation of biological adaptation and chemosensory mechanisms than when an entirely unrelated plant is colonised by an insect. Two theories are currently in vogue: *Evolutionary opportunism*[1], wherein with a larger distribution area of a species and a high degree of heterozygosity, changes for passive assemblage are increased, versus *Ecological opportunism*[1], wherein some insects simply exploit hosts constituting a larger resource without particular changes in habitat selection. Host plants are the basis of complex food webs, which can reduce the pressure of phytophagous exploiters. Plant structures as such are arenas for the 'competitive interaction' of the insect species exploiting them. In short, phytophagous insects exert a selective pressure that promotes diversification of defence mechanisms in plants.

Morphological resistance of plants to insect attack, more particularly the role of trichomes, has received considerable attention. Some of these trichomes may interfere with oviposition, attachment of the insect to the host plant and feeding, and their mechanical effects relate to density, erectness, length and shape. Some trichomes possess glands that exude secondary plant substances so that the plant may combine physical and chemical defences. Even if eggs are laid, many larvae do not survive because of the nutritionally inadequate diet. Most plants escape or survive the attacks of insects through the possession of thickened cell walls, increased toughness of tissues, proliferation of wounded tissues, solid stem, trichomes, surface waxes and silica in cell walls. Many plants possess extrafloral nectaries, which serve as attractants that defend the plant against other insects.

ROLE OF ALLELOCHEMICALS

Thousands of chemical compounds that act in one or the other manner are well known, and broadly classifiable into five major categories: nitrogen compounds, primary alka-

1. Zwolfer, H. 1982, *Proc. 5th Int. Symp. Insect-plant Relationships. Pudoc.* Wageningen: 287–296.

loids, terpenoids, phenolics, proteinase inhibitors and growth regulators relating to insect hormones. While allelochemicals in general mediate an interaction between two individuals belonging to different species, kairomones evoke in the receiver a behavioural or physiological response and allomones produce responses favourable to the producer. When the response is favourable to both producers and receivers they one known as synomones. The role of allelochemicals or secondary plant substances, so called because they play no primary role in metabolism, is also well known, although there is an imminent need to identify many more such compounds in as many plants as possible and to assess the importance of their influence on insect-plant relationships. Contact chemoreceptors and close range olfaction within the leaf boundary are significant for insect food selection. But the surface topography and the chemistry on and immediately above the leaf surface are equally important.

Phenolics, which are non-nitrogen compounds containing one or more hydroxyl groups attached to the benzene rings, have a role among the multitude of chemical signals that make up a plant and its environment. They are known to affect the nutritional quality of plants. The major groups of phenolics are phenylpropanoids, flavonoids and quinones. How far plant phenols provide a barrier to insect feeding is a question still being tackled, since they are known to have deleterious effects on larval growth. Dietary phenols may be dealt with by insects through avoidance sequestration/storage, absorption, metabolism and excretion. Compounds harmful to one insect may have little effect on another, even congeneric species. It is still far from clear how phenolics interact with the nutritional quality of the leaf to reduce its palatability. Some phenolics, such as tannins, have strong protein adsorbing properties; proanthocyanins or condensed tannins are feeding inhibitors, which also reduce digestibility; however anthocyanins promote pollinator attraction, and rotenone, an isoflavanoid, has insecticidal properties. Protein inhibitors in plants are found in large quantities in seeds, tubers and foliage, and the inhibitory activity of protein inhibitors is specific to digestive proteinases. Protein inhibitors are proteins or polypeptides that split bonds of proteins inhibiting the proteolytic activity of the enzyme.

Terpenoids, such as mono-, sesqui- and diterpenes possess the maximum range of functioning in the regulation of growth and development in insects. While monoterpenes act as attractants/repellents, sesquiterpenes and diterpenes exhibit considerable biological activity in relation to the action of toxins and hormones produced by plants. These plants are able to synthesise and sequester compounds non-toxic to the plant itself, but on being consumed by insects are activated into lethal cytotoxins. Several growth regulators, such as phytoecdysones and juvabione-like compounds, such as precocenes, have been isolated from plants. In insects feeding on terpene-containing plants, cytochrome P-450 is known to metabolise them to products, which could be excreted; it is equally well known that many terpenes induce cytochrome P-450 to higher activity. Such activities may influence the hormone balance or pheromone products in the insect, so that regulation of reproductive processes by these allelochemics is implicated. Hormonal and pheromonal research both in terms of naturally occurring chemical products in plants as well as intrinsic studies of their impact on the reproductive physiology of insects, would go a long way in promoting a better understanding of non-conventional methods of insect control.

A new class of regulating molecules in plants, oligosaccharides, which help to control growth, reproduction and defence against diseases, were recently discovered. These are fragments of the cell wall, released from the wall by enzymes. Plant cell walls are repositories of a large number of oligosaccharides. These are thought to regulate not only activation of defence mechanisms, but also aspects of plant product and morphogenesis.

There is an increasing need for a deeper understanding of the chemical perception of plants by insects with different host plant selection strategies. Generalists or polyphages use different chemical cues to recognise their preferred host, while the specialist host perception is mediated through key stimuli in their preferred host. By comparing the oviposition behaviour and the sensory physiology of adult insects with different host specificities and by analysing behaviourally active compounds, it has been postulated that the same fractions, which were neutral or stimulatory to specialists were highly repellent or deterrent to generalists. There is need, therefore, to isolate active compounds in order to evaluate their combined effect or interaction on oviposition behaviour. Another aspect relates to the plant stimulating vitellogenesis since in its absence ovarian activity is kept at a low level. If the plant stimulates mating, dependence of the female on the plant is greater, so that the adjustment of fecundity to the carrying capacity of the environment is better. For example, some phytophagous insects do not mate without eating the pollen of particular hosts; thus flowering stimulates vitellogenesis and induces the female to a state for oviposition. Such a stimulation of vitellogenesis will also occur when feeding on other plant parts; there are lacunae in our understanding of this problem. Host plants tend to induce the production of visual, olfactory and auditory stimuli in one sex, and host plant induction of sexual behaviour is an aspect deserving more incisive studies. It is well known that the discovery of larval host plants by adults is a prerequisite for oviposition, particularly by specialist insects.

SEQUESTRATION AND DETOXIFICATION MECHANISMS

Many insects sequester secondary plant metabolites for their own protection. Sequestration mechanisms in phytophagous insects include the acquisition of nutrients, adsorption of specific chemicals by insect chemoreceptors as well as uptake of ions enabling maintenance of osmotic balance. Many phytophagous insects have the ability to metabolise steroids to various degrees prior to their incorporation in the membranes. A host of other physiological processes such as utilisation of dietary phenylalanine and tyrosine for the formation of proteins are well known in some insects. It is also known that each insect species treats ingested plant allelochemics distinctively, so that a compound excreted by one insect becomes the main sequestration product for another. Phytochemicals such as volatile oils sequestered by bees to attract males or as pheromones in lek formation, production of pheromones as in scolytids, or production of gregarisation pheromones in locusts, are important for certain critical behavioural and physiological processes of insects. Well-known examples of sequestration include eugenol, vanillin, pinene and myricine by bark beetles from pine terpenes; and pyrrolizidine alkaloids by danaid and arctiid lepidopterans acquiring male sex pheromones. Sequestration is the result of physico-chemical and biochemical conditions, and involves differential organisation of exogenous chemicals into other molecules, membranes, cells, etc.

Absorption of nutrients by the gut and their subsequent utilisation by the body is fundamental in explaining how these chemicals are incorporated. The sequestration and storage of cardiac and cyanogenic glycosides and other toxic alkaloids and their utilisation in defence against predators are classic examples. Many more such instances await discovery, particularly with emphasis now being given to the role of natural plant products and insect attack. Sequestration represents the end product of a series of biochemical and physiological events, which may reflect absorption, metabolism of specific compounds and excretion of selected allelochemics[1]. The entry of a plant allelochemic into the gut of an adapted insect is known to trigger a series of reactions that may result in the compound being metabolised. Detoxification results from the metabolisation of the absorbed compound and this process often results in the sequestration of a product. Very little is known about the toxicities of allelochemics and their metabolites to be able to assess the significance of these processes.

Metabolic conversion of potentially toxic allelochemics to water-soluble products which can be easily eliminated or utilised or stored is effected by several enzymes—oxidases, hydrolases, transferases and reductases. Since lipophilic foreign compounds are hazardous in view of their large-scale occurrence in plants, these enzymes aid in their conversion from a lipophilic to a hydrophilic condition. Many natural plant chemicals are known to induce Mixed Function Oxidases (MFO) activity, which may mediate resistance. The midgut epithelium has a high potential for MFO production as well as of other detoxifying enzymes. Synergistic chemicals are also known, which may inhibit MFO enzymes. However, this is a relatively new area and not much is known about the functioning of naturally

[1] Duffey, $.$.1980 *Ann. Rev. Entomol*, **25 :** 447–477.

occurring synergists on the consumption and utilisation of plants. The MFO system is also believed to participate in the synthesis of pheromones molecules[1].

Recent efforts to study the antiherbivorous effect of phytoalexins have evoked considerable interest because they affect the feeding preference of adults and larvae of phytophagous insects. In some cases detoxification mechanisms exist to overcome the antibiotic effects of isoflavonoid phytoalexins, but not of substances like rotenone. While studies on the effects of phytoalexins on the feeding of several phytophagous insects have provided diverse results, some, for example vestitol and phaseolin, are known for antifungal activity and reduction of feeding by phytophagous insects. Others such as pisatin, genistin and coumestsrol may affect the feeding of one species, but not of others. Thus phytoalexins exert a selective effect[2]. Hence the role of phytoalexins in plant defences and of the mechanism of induced resistance may be a very potential field for future investigation, particularly because 'induced resistance' represents a new dimension in pest control strategies. Plant properties responsible for deterring the feeding of an insect or non-preference mechanisms, involve antibiosis, wherein the insect is totally prevented from feeding, and antixenosis when it is forced to feed on a particular plant, with no choice. These two reactions are equally important. Resistant plants are known to lack or possess very little of the normal kairomone, which is inhibited or blocked by antagonistic compounds. Antibiosis is the most evident form of resistance, often caused by toxic metabolites, and its effects are larval mortality in the first few larvae, abnormal growth rates, pupation and adult emergence failure, malformed or sub-sized adults, reduced fertility and fecundity, and inability to store food reserves. Whether a potential host is selected or not is therefore decided by a balance between physical stimuli and physical barriers, attractants and repellents, feeding deterrents, ovipositor stimulants and ovipositor deterrents. A good example is the most effective antifeedant and toxicant against many pest insects - azadirachtin – and available information has highlighted its direct role on the neuroendocrine system, as well its inhibitory action on gut motility in *Locusta.* In view of azadirachtin containing several principles, its potential in terms of the isolation and nature of activity of these principles is a fertile area of future research.

The exploitation of plant tissues by insects resulting in the abnormal growth called 'galls', is a specialised level of trophic strategy providing an optimal environment for rapid reproduction and abundant food for the larvae and adults of gall-forming insects. The development of nutritive tissues as well as of other meristematic tissues, capable of differentiation into various tissues, are very typical of gall formation. The biochemistry of gall formation has eluded cecidologists and the several explanations put forward are not very

[1] Ahmed, S. 1983, *Herbivorous insects: Host Selection Behaviour and Mechanisms.* Academic Press, New York, pp 257.

[2] Kogan, K. and Paxton, J. 1983, Natural inducers of plant resistance. In Brattsten L.B and S. Ahmed (ed) *Molecular aspects of Insects Plant Association.* Plenum Press, New York, pp 347.

convincing. Cecidogenesis tends to alter the composition of amino acids in the leaf, raising the soluble nitrogen level and, generally speaking, galling increases the level of total amino acids. Galls are often referred to as sinks withdrawing nutrients and cecidogenetic tissues also have an increased water content. Basically galling can be considered as a reaction to wounding and various hormones play a key role in the wound-induced process. Indoleacetic acid and gibberellic acid are known to accelerate mitosis and the combined activity of various hormones tend to increase kinetin concentration, leading to enhanced proliferation. In-depth investigation of the biochemistry of galling is very much needed to substantiate the several views now current. Equally important is the determination of the significance of plant growth hormones in the further reproduction of phytophagous insects, taking into consideration seasonal changes in the physiological state of their host plants. In addition, the temporal adaptation of the insect life cycle in relation to the phenology of the host plant also appears to be a decisive factor in phytophagous insects with specialised behaviour.

It is difficult to adequately pinpoint the specific parameters involved in insect-plant interactions, more so because the interaction constitutes a continuing process in space and time. With both the insect and the plant trying to outwit the other, the mechanisms involved in this process naturally vary from species to species and it is here that no broad generalisation is possible. Thus the study of as many species of phytophagous insects and their host plant becomes more obligatory, so that in the long run it will be possible to undertake an overall analysis of such interactions with reference to both generalist/specialist insects. The basic fact that a major determinant is the size of an insect's habitat and the distribution of the host plants must be recognised. In the successful achievement of such a colonisation, the qualitative and quantitative chemistry of the living plant in relation to behaviour and sensory physiology play a vital role, offering a better understanding of the sensory physiology in insect-plant relations. In this connection there is also a need to realise that phytophagous insects are regulators of plant growth, playing their role in 'density-responsive' regulation of the population densities and dynamics of the affected plants. The mechanism of resistance is known to a great extent, but gaps still exist in our information regarding the biochemical and genetic adaptations. The emerging frontiers of insect-plant interactions lie, however, in the exploitation of the nature of resistance in crop plants through modern DNA technology, gene splitting and gene cloning.

Ant-Plant Interactions

Ant-plant mutualisms are well developed since they depend on each other to increase their fitness. Ant inhabited plants are called as myrmecophytes. Plants like acacias have enlarged thorns (modified stipules) and ants hollow out these to use as nest sites. In some acacias ants inhabit stem swellings or galls just below the stipular thorns. Ants belonging to the genus *Pseudomyrmex* hollow out large areas of the thorns and distribute the colony among the numerous thorns. Swollen thorn acacias have extrafloral nectaries at the petiole, which secrete a solution containing water, sugar and amino acids. *Beltian bodies* are found at the tip of the leaves, which provide protein lipids for the ants. Ants collect Beltian bodies as soon as they are available. *Pseudomyrmex* colonies contain more than 30,000 ants.

A second group of myrmecophytes receive nutrients from ants and are the ant epiphytes, the plants producing hollow or inflated roots, hollow rhizomes or folded leaves. A plant structure generally inhabited by ants is called domatium. Best studied nutritional myrmecophyte is the plant *Myrmecoelia tuberosa,* with enlarged tubers containing empty broods are kept here and the ants deposit their refuse. Adventitious roots grow into the chambers containing ant refuse and absorb nutrients directly.

Another aspect of ant-plant interaction deals with seed dispersal and ant dispersal of seeds is called myrmecochory. The seeds have associated appendages that serve as food for the ants. For example elaiosomes are oil-containing appendages that are utilised by ants.

◆ Chapter 82

Insects and Host Plant Resistance

Host plant selection is a complex process involving host habitat finding, host finding, host recognition, host acceptance and host suitability. Each one of these major steps maybe influenced by the chemical composition of the host plant, their nutritional quality as well as secondary chemical substances which often play a major role. Other components of host selection involve: (a) insect utilisation of the host plant for food, oviposition, and shelter, (b) the effects of insect infestation of a plant, (c) the effects of the infested plant in terms of insect survival, colonisation, fecundity, growth and population build-up. In order to successfully utilise its host plant the insect must be versatile enough to complete all the normal sequence of events and failure at any step may confer an advantage to the host plant. It is generally seen that insects tend to multiply rapidly on a suitable host, while on a less suitable host plant they seldom prefer to colonise. Even if colonisation occurs they tend to multiply only at a low rate. Such differences in the suitability of host plant utilisation by insect are not only due to the preferences exhibited by the colonising insects, but also due to the inherent qualities of the host plant which facilitates insect colonisation. Thus the host plant forms an important 'island' for the insect, which determines its survival, growth, and multiplication rates. The inherent qualities of the host plant, which help to protect them from insect damages are collectively referred to as 'resistance'. In other words, resistance of plants to insects is the property that enables a plant to avoid, tolerate or recover from injury by insect populations, which would cause greater damage to other plants of the same species under similar environmental conditions. From an evolutionary point of view, resistance traits are pre-adaptive characteristics of plants to withstand the selective pressures of herbivore populations, thus increasing the chances for their survival and reproduction. This means that plants co-evolving with their insect pests must acquire a certain degree of resistance to enable their survival and a precise understanding of such host plant mechanisms for resistance would go a long way in tilling the balance in favour of the crops. The concept of insect resistance to crop plants was initiated by Painter* (1951), who recognised three basic components of resistance:

Preference/Non-preference: lnvolving plant characteristics that make it unattractive to insect pests for oviposition, feeding or shelter;

Tolerance: Referring to the capacity of certain plants to withstand the injury caused by the insects and to produce an adequate yield in spite of supporting an insect population at a level of damaging a more susceptible host; and

Antibiosis: Encompassing all adverse physiological effects on the life history of the insect of a temporary or permanent nature resulting from the ingestion of a plant by an insect, leading to decreased fecundity of size, increased mortality or shortened life span.

Though the concept of resistance was merely related to genotypes, it is equally well recognised today that resistance can be affected considerably by the condition in which the crop is grown. The degree of previous infestation, age or height of the plant may influence preference. The suitability of the plant for growth, survival or reproduction of insects has also a direct relationship with water stress, growth regulators, nature of fertilisers used, etc. In brief, the mechanisms of resistance to insects by plants are principally physiological, but subject to environmental variation. As such plant resistance to insects is complex and is seldom caused by a single mechanism or a single chemical. Plant resistance could also result from disruption of the normal sequence of events because of a reduction in the level or repression of the kairomones, or because of the enhancement of allomones. While some resistance traits are under genetic control, others may be viable and fluctuate widely under the influence of environmental conditions. Hence, the mechanism of resistance may be classified as those that are under the primary control of environmental factors (ecological resistance) and those that under the primary control of genetic factors (genetic resistance).

Ecological Resistance

Ecological resistance does not result from genetic characters inherent in the host plant, but from some temporary shifts in the environmental conditions favourable to the otherwise susceptible host plant. Painter (1951) has classified ecological resistance as 'Pseudo-resistance', since plants that escape insect attacks by this mechanism may in fact be susceptible if the pest occurs at the right time. Pseudoresistance may be further classified into 'host

* Painter, R.H. 1958. Resistance of plants to insects. *Ann. Rev. Ent.,* **3**: 267–290

evasion' and 'induced resistance'. Survival of an oligophagous insect, on a plant is not only determined by the selection of the right host plant, but also of the proper stage of development. The phenologies of the plant and of the insects must be synchronised so as to enable a plant structure to exist, when a particular stage of the insect needs it. However, an alternation in plant growth patterns that result in asynchronies of insect-host phenologies result in a type of resistance called as 'host-evasion'. The characteristics of resistance are also bound to vary with the age of the crop plants. Phytophagous insects directly depend on their host plants for food and the more specialized the association, the greater is the 'physiological dependence' of the insects upon the plant. Synchronies may be induced by early or late planting of certain plant varieties. The early varieties of soybeans planted were found to escape from the attack of the bean leaf beetle, *Ceratoma trifurcata*, since by the time the beetle emerged in the early part of September, most plants had already matured, being ready to harvest. Thus these beetles cannot harm the crops, since the mature pods are not an adequate food. Early sowing of the castor variety Dominica resulted in lesser infestation and 'hopper burn' from the leafhopper, *Empoasca flavescens* than those sown late in the season.

Certain environmental conditions may tend to alter the physiology of a plant to such an extent that it becomes unsuitable as a host. Under such conditions the responses of crop plants to normal cultural practices such as fertilisation and irrigation may be altered to bring about drastic quantitative or qualitative changes, making the host plant unsuitable for colonising insects. In other words products made and intentionally applied tend to influence the behaviour of insect, to plants. These products include, apart from fertilisers herbicides, fungicides, growth regulators and insecticides. For example, at high nitrogen levels, insects usually respond with an increase in survival and faster rates of development. Aphids are particularly sensitive to the levels of potassium, even in the presence of high nitrogen. Thus the possibility of bringing a balance between nitrogen and potassium could induce the crop plant to combat the pest attack Similarly, application of Maleic hydrazide to broad bean plants increased mortality and reduced fecundity of aphids and growth retardants such as chlormequat also have been known to appreciably increase resistance mostly due to reduced fecundity of females or increased mortality of offspring. Another interesting induced resistance factor is induction of resistance involving accumulation of compounds with resistant populations, as for instance, feeding by the pea aphid on alfalfa induces an increase of coumestrol that may affect feeding by other pea aphids. Other examples are production of phenolics by cotton bollworm on cotton, cucurbitacins by the striped cucumber beetle on squash etc. Mechanisms of induced resistance relate to changes in the physiological status of the plant, in the nutrient concentrations, in the concentrations of allelochemicals, and the most significant of all, the *de novo* synthesis of phytoalexins.

Genetic Resistance

Genetic resistance includes mechanisms based on whole expression of inherited characters which although influenced by the environment, is not strictly under environmental control. This includes non-preference, antibiosis and tolerance mechanisms of resistance. However, in the strict sense the term 'non-preference' refers to a behavioural response of the insect to a plant, whereas 'antibiosis' and 'tolerance' refer to plant characteristics. The term 'antixenosis' is used to describe the plant properties responsible for non-preference. If a plant deters feeding by an insect, the mechanism of resistance may be classified as 'antixenosis' or 'antibiosis', the choice of a host plant being affected by an array of positive and negative factors. The positive factors include the undesirability of the host plant (antixenosis) leading to the avoidance by insect because of the absence of certain physical stimuli, attractants, feeding stimulants, and ovipositional stimulants. The negative factors include the unsuitability of the plant (antibiosis) or the host plant preventing the activity of insects due to the presence of certain physical barriers, repellents, feeding deterrents, and ovipositional deterrents.

Non-preference

The phenomenon of non-preference is the first and foremost step operating in the catenary process underlying host plant selection by any phytophagous insect, when the insect has located its host plant. For an understanding of the mechanism underlying non-preference, the behaviour of the insect should be thoroughly understood. The behavioural responses shown by insects due to the undesirable attributes of the host may be due to physical, chemical or environmental factors, which restrict the insect utilising the plant for normal feeding and oviposition. At least two types of non-preference have been observed viz. one, which can be manifested only in the presence of the preferred host, and the other that can be demonstrated in the resistant plant even in the absence of the preferred host. For instance, the tobacco hornworm, *Manduca sexta* refused to feed on preferred plants, but larvae with maxillae removed sometimes consumed the plants without any adverse effects.

In most phytophagous insects non-preference due to oviposition and feeding generates a series of complex responses depending upon the environmental features and host characteristics. As applied to resistance, non-preference may represent one or more breaks in the chain of responses leading to feeding or oviposition. These breaks could be: (a) the absence of arrestant or attractants; (b) the presence of a repellent; or (c) an unfavourable balance between arrestant and or attractant on the one hand and repellent on the other.

Hence, the chemical composition of the plant is of fundamental significance in their acceptance or rejection of food or oviposition by insects. In many cases feeding inhibitors are of primary importance in determining the plants susceptibility to consumption.

(a) Non-preference due to Physical Factors The physical factors influencing non-preference include visual and tactile stimulus. Among the visual cues affecting orientation of insects towards a host plant, colour and shape appear to be important. Insect attraction to foliage colour has been most intensely studied in homopterans. In some aphids, discrimination between plants or portions of plants in particular physiological conditions may be at least partly accomplished on the basis of differences in saturation of intensity or reflected light. With respect to saturation in the aphid, *Hyalopterous pruni* seeking plants like *Phragmites* as summer hosts, they alight in greater numbers on unsaturated yellow than on saturated yellow. They appear to use the same saturation discrimination basis for discerning their unsaturated *Phragmites* host from non-hosts. With regard to intensity differences, some aphids are more attracted to higher reflectance from newly developing leaves (the yellow appearance correlated with high available nitrogen content of the sap) than to the lower reflectance of mature green leaves of the same plant. The apple maggot fly, *Rhagoletis pomenella* is also attracted to the yellow hue of foliage for feeding and resting and to the form of the fruit for mating and oviposition. The behavioural repertoire of the onion fly *Delia antiqua* suggested that apart from chemical cues, visual and structural cues are also important in stimulating egg deposition by the insect. Thus for herbivores that respond positively to the visual stimulus of foliage reflectance, green pigments, and to a much greater extent yellow pigments, have proven valuable in management programmes against various homopterans, beetles and flies when incorporated into traps for monitoring or direct control. Similarly, for insects attracted by the form of host plants or plant structures, mimics of appropriate shape, size, and hues, alone or in combination with olfactory stimuli, have constituted powerful methods of population monitoring or direct control.

(b) Non-preference due to Morphological Factors The morphological factors interfere physically with locomotor mechanism and more specifically with the mechanisms of host selection, feeding, ingestion, digestion, mating and oviposition of insects. Such physical barriers are also mediated by the presence of trichomes, surface waxes, silication, or sclerotisation of tissues. In addition, allomones affecting insect behaviour and metabolic processes may occur in plant morphological structures (trichomes on bracts).

Plant pilosity was frequently postulated for being involved in susceptibility or resistance to insects. The most notable success was the control of the cotton jassid, *Empoasca* spp., by means of plant resistance to oviposition. Growing soybean varieties with dense hairiness of foliage manifested both preferences and resistance to leafhoppers. Studies on the resistance of castor (*Ricinus communis*) to the leafhopper, *Empoasca flavescens* showed that the infestation of the insect was directly or indirectly related with plant characters of castor varieties. Jassid incidence was found to be positively correlated at a highly significant level with the plant height, intensity of waxy bloom coating, leaf area, age of the plant at flowering, number of nodes, internode length, petiole length, leaf sinus depth and number of leaf lobes etc. For feeding and oviposition the insects preferred Dominica (susceptible and C3). In addition, hoppers preferred middle and bottom leaves rather than the top leaves within the plant. Besides hairiness, various other characters like, the width of leaves and palisade tissue, thickness of midveins, density of trichomes and angle of insertion of trichomes also had an impact on resistance or susceptible behaviour of varieties of cotton to jassids.

The bollworm, *Heliothis zea* showed preference for extremely pubescent rather than smooth cotton plants. On the contrary, the oviposition of the leaf beetle, *Oulema melanopus* was not only low in pubescent varieties, but the oviposited eggs also were susceptible to dessication and only less than 10% hatched. Some insects also exhibited preference for either smooth or rough surfaces. For example, the cowpea bruchid, *Callosobruchus maculatus*, prefers smooth coated and well-filled seeds to rough and wrinkled varieties for oviposition.

In many cases the nature and distribution of epidermal trichomes and glands protect crop plants from the attack of insect pests. Glandular trichomes and plant glands exude sticky substances that entraps and immobilises small insects, or they may contain toxic constituents which spill into the surrounding tissue when the glands rupture, making the plant unpalatable for insects. The wild *Solanum* species, *Solanum berthaultii* and *S. polyadenium* are defended by glandular trichomes on its foliage, secretions of which entrap and immobilise the green peach aphid, *Myzus persicae*, the potato aphid *Macrosiphum euphorbiae*, and the potato leaf hopper, *Empoasca fabae*. Two types of glandular trichomes were identified to be associated with insect resistance, a short type with a four-lobed gland at its apex (type-A), and a longer multicellular trichome with an ovoid gland at its tip. Mortality of fourth-stadium *M. persicae* and encasement of tarsi and labia by type-A exudate increased with a rise in density and volume of type-A trichomes. Similarly, wild tomato, *Lycopersicon hirsutum* f. *glandulaum* is covered with trichomes, which contain 2-tridecanone, the level of which is much lower in the domestic varieties. This substance proved toxic to *Manduca sexta* and *Heliothis zea* and this toxic compound was significantly more abundant on foliage of plants grown under long day regimes.

DIMENSIONS OF INSECT-PLANT INTERACTIONS

Several morphological and anatomical characteristics of potential host plants may present barriers to insect feeding and oviposition. Resistance to the striped rice borer, *Chilo suppressalis* (Walk.) was observed in rice varieties whose leaf sheaths had closely packed vascular bundle sheaths and a large number of sclerenchymatous layers, and in rice plants whose stems and leaf sheaths contained high amounts of silica. The larvae feeding on rice varieties containing high amounts of silica exhibited the typical antibiosis effects and worn-out mandibles. Anatomical characteristics that confer resistance are hard wood stem with closely packed, tough vascular bundles, making larval entry and feeding difficult. In sorghum all resistant varieties were characterised by a distinct lignification and thickness of cell walls enclosing the vascular bundle sheaths within the central whorl of young leaves. Similarly, the mechanism of resistance in brinjal to the shoot borer, *Leucinodes orbonalis*, was attributed to compact vascular bundles in thick layer with lignified cells and low pith area.

Another good example is the interaction between the onion thrips, *Thrips tabaci* and varieties of onion. Of the many varieties tested, 'White Persian' was outstanding in its resistance showing only little injury. Two or three characters tend to restrict onion thrips population viz., shape of leaves, angle of divergence of the ten innermost leaves and the distance apart of the leaf blades on the sheath column. In most varieties the leaf blades are flat and the two opposite blades are closely adhered protecting the larvae. In the 'White Persian', the leaves are circular in circumsection reducing protection to a minimum. The wide angle between the two innermost emerged leaves in young plants help to restrict the population and there is a greater vertical distance between leaf blades restricting the sheath column.

(c) Non-preference affecting Oviposition Most phytophagous insects deposit their eggs on or near the host plant to be utilised by their progeny. Oviposition is the culmination of a series of behavioural events, the first component of which is the orientation of the gravid female to the prospective host plant, which is selected from among the array of plants available. Following orientation to the plant as a whole, the insect orients to different plant parts in the selection of a specific oviposition site. Plant characteristics tending to prevent oviposition may do so by failing to provide the appropriate stimuli for orienting towards the host plant or for ovipositing the eggs.

Orientation to a prospective host plant may involve normal as well as chemosensory stimuli. The importance of plant-borne attractants in insect orientation has been demonstrated in many studies, and the role of olfactory stimuli in some instances of plant resistance has also been confirmed. For instance, an up-wind orientation of desert locust in response to grass odours has been reported. The odours of non-hosts may fail to evoke any orientation response, or they may elicit a negative reaction in which the insect moves away from the odour source. Upon arriving at the prospective host plant, the insect is responsive to stimuli that will release the subsequent components of the ovipositional behavioural pattern. Oviposition is seldom indiscriminate over the surface of the plant or in the surrounding soil, but most frequently on selected plant parts. The specific sites selected may vary according to leaf maturity and the physiological state of the plant. Specific ovipositional stimulants may he involved such as a stimulant for the carrot root fly, *Psila rosae*, was found in carrot leaves and identified as trans-1, 2-dimethoxy-r-propenyl-benzene. Oviposition by the onion maggot was stimulated by a number of organic sulphur compounds, most effective of which was n-propyl disulphidede and n-propanyl mercaptan, both of which are normal constituents of onion.

The role of inhibitory stimuli in the choice of oviposition site by phytophagous insects has been emphasised. The acceptance or rejection of a plant usually depends on contact with the plant surface or through probing after landing. Specialist insects will oviposit if the right stimulant is present, whereas acceptance by generalist is governed to a large extent by the absence of deterrents. Specialists may also be deterred by non-host components, which can interfere with the response to positive signals.

Non-preference to Feeding The feeding behaviour of phytophagous insects is an important factor in determining the resistance of host plants to the attack of insects. Insect larvae hatching from eggs deposited on a host plant are usually confined to that plant for the whole of their immature, feeding stages. Feeding involves a series of stereotyped behavioural components and such behavioural pattern is manifested only in response to the appropriate combination of external releaser stimuli. The host plant is normally the source of releasing stimuli, and resistance may result from failure of the plant to provide the stimuli required for one or more components of the sequence, or because the plant provides adverse stimuli that tend to prevent the release of the behaviour.

The range of food plants of an oligophagous insect has, in a number of instances been shown to be characterised by the presence of identical or related chemicals that stimulate the insects' feeding. The classical demonstration of the relationship of the feeding specificity and taxa-correlated chemical factors is the instance of larval feeding of *Papilio ajas*. Umbelliferae, on which this butterfly feeds almost exclusively, contains a group of related essential oils that attract the larvae. Plants not containing these substances were not attractive, nor would the larvae attempt to feed on them. Similarly, feeding of larvae of *Plutella xylostella* is confined entirely to the plant family Cruciferae; a number of mustard oil glucosides that commonly occur in cruciferous species were shown to be feeding stimulant for the larvae. In addition to the nutrients a number of secondary plant substances are involved in such cases of specialisation, even though the primary function of these compounds in the evolution of the plant is believed to be in defense against herbivores. Such compounds are powerful feeding deterrents or antibiotic agents providing protection from generalist insects. The idea of utilising feeding deterrents as a means of protecting crops from insect damage has received a lot of attention in the last few years, and large screening programmes have uncovered several promising compounds present in plants, and the introduction of feeding deterrents into crop plants through breeding programmes would appear to be an ideal solution to many pest problems.

Antibiosis

When a plant is resistant by exerting an adverse effect on insect growth and development, the nature of resistance is termed as 'antibiosis'. The adverse physiological effects may be of a temporary or permanent nature and mostly inflicted due to the presence of certain toxic compounds present in the host plants. The chemical basis of plant resistance can be viewed from two perspectives; a plant may be resistant owing to the presence of certain plant chemical(s) such as growth inhibitors, feeding deterrents repellents and physiological toxins or because of the low concentrations or absence of certain chemicals such as essential nutrients, feeding stimulants, attractants, etc.

(a) Presence of certain Growth Inhibitors A unique example of the significance of a plant chemical in plant-insect interaction has been demonstrated in cotton. For instance the inhibitory effects of four types of cotton constituents, condensed tannis, flavanoids, terpene aldehydes and cyclopropenoid fatty acids, upon the larvae of *Heliothis virescens, H. zea* and *Pectinophora gossypiella* appears to be striking. Breeding cotton varieties with increased gossypol content render the plant virtually immune to most of its lepidopterous pests. Larval growth was found to be greater on glandless than glanded cotton strains. The antibiotic activity of gossypol, tannins, and anthocyanins have also been assessed on the spotted bollworm, *Earias vittella*. The cotton constituents that show antibiotic activity towards insect pest are biosynthetically produced through either the acetate or shikimic acid pathways. In the case of glandless varieties, which do not contain high concentration of gossypol, a different factor is responsible which protect the plants from the attack of lepidopterous larvae. It is now found that condensed tannins can suppress *Helicoverpa* larval growth, development and reproduction. Anti-growth activity of condensed tannins appear much more effective for early larvae of *Helicoverpa*.

Tannins have been considered as an important secondary plant component responsible for acting as feeding deterrents against several herbivores. There are in fact two groups of tannins. The hydrolysable tannins and derivatives of simple phenolic acids such as gallic acid and its dimeric form, hexahydrocydiphenic acid, combined with the sugar, glucose. The condensed tannins have a higher molecular weight and are oligomers formed by condensation of two or more hydroxyflavanol units. The protein- precipitating properties of the tannins in ingested food result in poor digestion and consequently effectively reduce the nutritive value of the food. They combine with protein, often irreversibly, by forming bonds with the peptide and other functional groups and such bonding prevents proteins from being attacked by trypsin and other digestive enzymes. The importance of tannins in controlling the feeding of winter moth, *Opheroptera brumata* larvae on oak trees has been established. The oak caterpillars feed on the leaves in the spring but abruptly ceases feeding in mid-June, turning to other tree species for sustenance. It was established beyond doubt that the immediate cause of the change in feeding habit in the winter moth is due to the increasing repellency of the leaf; the tannin and protein, normally compartmentalised in different parts of the cell are brought together and the protein undergoes complex formation. As tannin content increases during the season, more and more of the protein becomes complex. This seriously reduces the digestibility of proteins.

The weevil, *Hypera postica* feeds almost exclusively on *Medicago* spp. and occasionally on the related *Melilotus* and *Trifolium*. The rejection of other Leguminosae was due to the presence of high concentration of coumarin. Feeding deterrents including demissine, dihydro-o-solanin, leptines, solacaulin, solanin, and tomatin from various species of *Solanum* for the Colorado potato beetle, *Leptinotarsa decemlineata* have been recognised. It is interesting that deterrence to beetle attack is closely dependent on chemical structure and small changes in part of the deterrent molecule acts on the insect at the membrane level, which are required by the beetle for ecdysone synthesis. Since alkaloids of *Solanum* are in fact steroidal molecules, it is also possible that they have a direct effect in blocking ecdysone biosynthesis. Information on the deterrent properties of demissine is clearly of practical value since breeding experiments with *S. demissum* and *S. tuberosum* yields resistant varieties to the beetle attack.

Several deterrents to insect-feeding isolated from weed and crop plants were found to be very effective pest control agents. For example, a hexane extract of the seed of neem, *Azadirachta indica* and several of its chromatographic fractions significantly deterred feeding by three species of scale insects, citrus red mites and woolly whiteflies, a pentane extract of nutmeg, considerably deterred feeding by adult boll weevils, while an ether extract deterred feeding by adult boll weevils. Many diterpenes and triterpenes have antifeedant properties, those that are more oxygenated being more efficient viz., Azadirachtin against many insects like *Schistocerca*, clerodendrin (from *Clerodendron*) against *Spodoptera litura* etc. Two diterpenes from *Cinnamonum zeylanicum* possesses ability at low concentration to inhibit larval ecdysis in *Bombyx mori*.

Soluble silicic acid was isolated as a sucking inhibitor for the brown plant hopper, *Nilaparvata lugens* from water-soluble extracts of rice leaf sheaths. Silicic acid is presumed to be concentrated in the peripheral tissues outside the phloem and to play a significant role in the localisation of sucking sites in the host by preventing an erroneous intake of parenchyma cell sap. In addition, oxalic acid was another substance identified as sucking inhibitor from rice plants, with special reference to the varietal resistance of rice to the brown plant hopper. Other organic acids such as maleic acid, itaconic acid, benzonic acid and salicyclic acids were also found to be strong sucking inhibitors. Among the decarboxylated derivatives of aromatic amino acids, phenethylamine, tyramine, and hordenine were found to exert a marked sucking inhibitor effect. In addition recent investigations on the chemical factors involved in varietal resistance of rice to the brown plant hopper showed the existence of oxalic acid in significant amounts in resistant varieties compared to susceptible ones.

(b) Presence of certain Toxic substances Deterring Feeding A wide range of chemicals occurring in the host plant have been tested on the short term feeding effects (feeding deterrence) and long term physiological effects (impairing growth and development) of acridids. When extracts of 187 graminivorous species were provided, *Locusta migratoria* rejected 98 of them due to unpalatability. In the polyphagous species, *Melanoplus bivittatus* it was found that several secondary compounds, including alkaloids, a glucoside and a saponin, inhibited drinking behaviour and reduced the food intake. Sometimes morphological differences also results from feeding on different plants, the most obvious being wing development. It has been observed that a relatively high proportion of brachypterous adults were produced in adult *Schistocerca* if the nymphs were fed with Lucerne. Instances such as nymphs of *Zonocerous variegatus* surviving less on *Newbouldia*, extracts of *Medicago* added to diet causing increased mortality to the first instar of *Melanoplus femurrubrum* and substances like nornicotine, solanine, tomatine, digitonin or saponin added to the diets, in amounts equivalent to those in plants, inhibited the survival of acridids are some of the other antibiotic effects.

Not only structural analogues of amino acids, but also essential amino acids themselves can be deleterious, if they are ingested in excessive quantities or if they are not in balance with other amino acids. Ironically, the indispensable amino acids are generally less well tolerated in excessive amounts than are the dispensable ones, but non-protein amino acids are certainly much more toxic than protein amino acids.

Certain 'antivitamins' are also reported to inhibit insect growth. The active compound in fern was identified as an enzyme (thiamase I) that breaks down thiamin. Bracken fern also contains caffeic acid, which has antivitamin activity. Similarly catechol has also been reported for its growth inhibiting and toxic effects on insects. In addition, plant compounds known to inhibit trypsin and chymotrypsin (protease inhibitors) are found in peas, corn, barley and a wide variety of other plants.

Tolerance

Tolerance represents the relative ability of a plant to suffer loss of yield due to its innate capacity to grow and reproduce itself or to repair injury to a marked degree, than that manifested in an equally susceptible host variety. Tolerance is a promising candidate in the pest management programme because of certain innate advantages. Firstly, it enables the host to withstand damage without the use of chemicals to decimate the pest populations. Secondly insects are not known to have developed counter-measures to combat it successfully unlike the development of more virile and aggressive new biotypes for overcoming non-preference and antibiosis. Tolerance is also a natural agronomic procedure that reassert the stability of environment vis-a-vis the perennial host and the pathogen.

Tolerance, like other resistance components is relative and may occur in varying levels. It may also occur in combination with other components of resistance. Tolerance may thus be defined as the level of pest infestation that cause economic loss to other varieties of the same host species. It has also been considered to be a specific/discriminatory (monogenic) resistance as a means of protecting plants from pest damage. Several varieties of rice have been developed with tolerance against the brown plant hopper, *Nilaparvata lugens* based on characters such as plant damage, plant weight loss and yield reduction due to insect injury.

Several chemicals have been found to be responsible for the non- preference mechanism in resistant plant varieties through non- preference for oviposition and allied activities for successful establishment of an insect species on a crop. The phenolic resistant principles present in the host plant tissues of such crops on *Gossypium hirsutum, Abelmoschus esculentus* and *Cajanus cajan* and the antibiotic effects of some cotton resistant principles such as resorcinol, gallic acid and phloroglucinol on *Helicoverpa armigera* are well known. Further the significance of the cotton resistant principles such as tannic acid and pyrogallol to *Helicoverpa armigera* and *Spodoptera litura* appear to be species specific.

◆ Chapter 83

Insects-Weed-Crop Interactions

The wild ancestors of crop plants or original wild races have been the basic material from which the crops of today have evolved. Similarly grain and oil crops and vegetables are known to be evolved from wild weed species. For example, the oat *Avena sativa*, is derived from the wild weed *Avena fatua. Panicum miliaceum*, the millet is evolved from the weed *Panicum spontaneum*, while the Italian millet *Setaria italica* was evolved from barnyard grass *Setaria viridis.* Ragi (*Eleusine coracana*) originated from the weed species *Eleusine indica.* So in many of these cases weeds serve as reservoirs of variability and through occasional hybridisation are able to exchange genes. It is, therefore, natural that wild germplasm is always involved in order to produce more productive as well as disease resistant varieties such as *Oryza andamanensis*, the wild rice, which is rust resistant. Similarly resistance to plant hoppers in *Oryza officinalis*, a wild rice species, has been transferred to *O. sativa.*

However, weeds are so prevalent that they are an important component of agroecosystems. The fact that many pest species colonise on weeds, and breed successfully reveals that they can migrate to the crop and inflict severe damage at any time. This is more so when the growing period of crop plants synchronise with that of the weeds. Instances where there are definite host-plant successions between crops and weeds are also on record. Thus a knowledge of the nature of colonisation of insect pests and their population build-up on crop and weed hosts become essential to understand the interactions between insects, crops and weeds.

Acridid-Weed-Crop Interactions

Weeds provide large, probably an overwhelming, proportion of food for the desert locust, *Schistocerca gregaria* and thus this natural vegetation is effectively exploited by the continually nomadic populations of this pest. In view of the preference of *S. gregaria* for breeding in arid areas that are dry and therefore unsuitable for the growth of crop plants, wild weed hosts occurring in abundance in these locations assume an important role in the ecology of the desert locust.

Although in general, grasshoppers like *Oxya nitidula* prefer graminaceous and cyperacous hosts, conforming to the 'graminivorous type' of acridids, the developmental stages show feeding preferences in terms of the first and second instar larvae feeding on weed hosts and the third, fourth, and fifth instar larvae prefering to feed on crop plants. On the other hand, the cotton grasshopper *Cyrtacanthacris ranacea* feeds exclusively on malvaceous hosts including crops like *Gossypium hirsutum* and *Abelmoschus esculentus* as well as on weeds like *Abutilon indicum* and *Sida rhomboidea*, displaying a regular movement between the crop plants and weed hosts depending upon their seasonal availability.

Truxalis indicus feeds exclusively on monocots specially grasses, while *Orthacris maindroni* feeds on dicots and *Atractomorpha crenulata* on both monocots and dicots.

Aeolopus thalassinus, recognised as a pest of fibre crops, besides showing differences in the rate of development when fed on different weeds, viz. *Cyperus rotundus, Panicum maximum* and *Cynodon dactylon*, also varies in biotic potential with the maximum fecundity shown when fed on *C. rotundus*.

Thrips-Weed-Crop Interactions

The nature of weed-crop interactions with respect to the seasonal fluctuation of insects has been investigated in detail in phytophagous Thysanoptera. The role of the weed *Chloris barbata*, abundant in fields of *Pennisetum typhoideum*, as an alternate host of *Chirothrips mexicanus* is well known. The inflorescence of *Echinochloa crusgalli* also harbours numerous adults and larvae of *Haplothrips ganglbaueri*, the weed acting as an important alternate host for the thrips in paddy fields. *Caliothrips indicus* an important thrips pest of groundnut, is also found to colonise in large numbers on the weed host *Achyranthes aspera*, almost throughout the year, although its infestation on groundnut is seasonal. In Tamil Nadu, groundnut is grown twice a year, as irrigated and rain-fed crop, infestation of thrips was evident on 15 to 20 days old seedlings. The annual weed, *A. aspera* usually appears by August in groundnut fields and acts as a reservoir for this pest. The density of this weed declines from March and with the onset of the crop in June, *C. indicus* migrates from *A. aspera*. The peak population of the pest, both on the crop as well as on the weed was evident during September. With the increase in weed density there was a rapid migration of *C. indicus* from the crop to the weed. Similarly, *Zaniothrips ricini*, another thrips pest of castor, *Ricinus communis* has also been noticed to utilise the weed hosts, *Datura stramonium* and *Calotropis gigantea*. On castor, *Z. ricini* appeared during October and by January the peak population was evident with a decline thereafter. This decline of *Z. ricini* population on castor was immediately followed by the appearance of thrips on *Calotropis* and *Datura stramonium*. In this case both the weeds act as alternate hosts only for about two months.

Lygaeids-Weed-Crop Interactions

The milkweed bug, *Spilostethus pandurus* besides feeding on the crops *Gossypium hirsutum* and *Sorghum vulgare* is recorded as a pest of gingelly (*Sesamum indicum*). Similarly, the milkweed bug, *Spilostethus hospes* was observed causing damage to the seeds of *Solanum melongena, S. nigrum, Helianthus annuus* among the crop plants, besides feeding on the milkweed *Calotropis gigantea* and the weed *Vernonia cinerea*. Regular population monitoring indicated that the weed hosts served as reservoirs to sustain the population until the favourable crop season.

The nature and extent of survival, growth and reproduction of insects on crop and weed hosts ensures not only the suitability of the crop for the colonising species of insects, but also reveals the ability of different weed species to harbour different species of insects. The growth rate and fecundity of the lygaeid, *Oxycarenus hyalinipennis* and the mirid, *Cryptopeltis tenuis* showed significant differences when colonised on crop and weed hosts . Apart from cotton, *O. hyalinipennis* feeds on a number of alternate malvaceous host plant seeds viz. *Abelmoschus esculentus*, *Abutilon* sp., *Sida* sp. etc. The growth rate and fecundity were highest when reared on cotton seeds, than on other host plants. Similarly, the survival, post-embryonic development and reproductive efficiency of the tomato mirid, *C. tenuis* on crops and weed plants appear equally effective.

Host Plant Switching

Another aspect relating to the population patterns of insects on crop and weed hosts is host plant switching which is normally encountered when the crop/weed dries up, the exact stage of the host plant is not available for the insect to feed, or if there is any nutritional inadequacy so that insects tend to disperse to plants of more nutritive value for feeding and breeding. For example, assessment of the population trends of the mirid bug, *Cyrtopeltis tenuis* on tomato (*Lycopersicon esculentum*), ash gourd (*Luffa cylindrica*) as well as on the weed hosts, *Cleome viscosa* and *Gynandropsis pentaphylla* revealed a definite pattern of host plant switching depending upon the host plant availability and maturity. Peak population of *C. tenuis* on ash gourd occurs during May, declining rapidly during June and July.

By the end of July, ash gourd is removed from the field. The bugs then disperse from the cucurbitaceous plants and colonise on the weed, *Cleome viscosa.* The decline in population during June and July is related to the senescence of the vines. Population of *C. tenuis* increases on *C. viscosa* during August, but from September to November they disperse to another weed host, *G. pentaphylla.* As the cultivation of tomato takes place from December to January the bugs move on to these plants for subsequent feeding and breeding. The population slowly increases on tomato and reaches its peak during February and is at a low level up to the end of April, thereafter subsequent dispersal to ash gourd during May is observed depending upon the availability of host plants.

Weeds Harbouring Natural Enemies of Pests

Many instances can be cited with regard to natural enemies with free living stages that feed on the pollen and nectar of wild plants and with predatory/parasitic stages that feed on prey or hosts on wild plants. Flowers of many weed plants provide sumptuous food for natural enemies, for example, adults of some Syrphidae and parasitic Hymenoptera. The giant ragweed, *Ambrosia trifida*, is recognised as supporting a host of the first generation of the parasitoid, *Lydella grisescens*, which then causes notably increased parasitism of European corn borer, *Ostrinia nubilalis. A. trifida* also supports an important host of parasitoids of boll weevil, *Anthonomus grandis* and Orient fruit moth, *Cydia molesta.* The syrphids, *Melanostoma* spp. laid more eggs on brassicas infested with weeds than on weed-free brassicas.

Although several researchers have demonstrated that certain weeds serve as reservoirs of alternate hosts and prey for natural enemies, only a limited number of weeds appear to be tolerated in fields of cultivated crop plants since the weeds can hamper the economic threshold level and compete with the crop. Hence the trend envisaged now is to maintain certain specific weed associations in crop areas to provide supplementary food for entomophagous insects. However, the objective of maintaining a desired weed composition at a limited density has been seldom achieved. The use of weeds in vine yards of California to manage the grape leaf hopper egg parasitoid *Anagrus epos* was in vogue.

Many of the predators can be increased through seasonal manipulation of selected weeds and effectively used as natural enemies of important crop pests. Early stages of crop growth, the presence of specific weeds may act as a reinforcement for natural enemies of crop pests. They thus sustain the population of predators prior to the onset of the pest. Later these control agents tend to migrate from the weedy areas to the crop. For example, most of the predators like *Geocoris* spp., *Podisus maculiventris*, *Zelus cervicalis, Callida decora*, etc., and several coccinellids, syrphids and dolichopodids are seen on weeds like *Solidago altissima, Chenopodium ambrosoides* and *Heterotheca subaxillaris* in spring and later occur on corn in nearby fields. A chemical interaction between the leaf hopper, *Empoasca kraemeri* and two grass weeds *Eleusine indica* and *Leptochloa filiformis* was noticed when grown on the boundaries of the bean field exerting a repellent and/or masking effect decreasing its colonisation efficiency. Weeds also play an important role in reducing crop apparency and increasing the anti-herbivore chemical defence of certain crops.

◆ Chapter 84

Signalling Chemicals: Pheromones

The intermittent flashings of fireflies and glow-worms and the chirping of crickets are well-known signals attracting mates, but long distance mating calls involves chemical odours and the chemistry of sex attraction has drawn the attention of entomologists the world over. Chemical signals control insect behaviour, the signals involving volatile organic substances active in very small amounts, released by one insect to affect another of the same species.

Pheromones, as these substances are called, are involved in every aspect of insect life, feeding, sex, aggregation and oviposition, so that chemical communication in biological systems has come to be widely recognised. Chemical signals form an universal attribute of life existing within cells, within and in between organisms. Together with acoustic and visual modes of communication, chemical signals of the olfactory type such as pheromones serve an enormous variety of purposes, particularly in relation to feeding, reproduction and protection.

In social insects as in honey bees, they are essential means of communication between the castes. A practical incentive for the study of insect pheromones is evident since their identification provides a means of monitoring population of major pests of agriculture and forestry.

Naturalists of yesteryears were intrigued by the ability of female moths to attract males over long distances of several kilometres and it was in the thirties that this attractivity was identified as due to volatile chemicals, the functional antennae of the moths being critical for the location of females. The complexity and variety of chemical structures observed in diverse insect species point to the amazing ability of insects to sequester and synthesize unique chemical blends. It was in1939 after 30 years of ceaseless research that the Nobel Prize winner Butenandt identified the sex attractant of the silk moth as Bombykol, extracted from half a million female silkworm pheromone glands.

This was the beginning of our understanding of biocommunication in insects leading to a better appreciation of signal systems, their decoding and utilisation as adaptive strategies. The communication system involves release of specific chemical from a producer or emitter, the transmission of these chemicals in the environment to a receiver and processing of the signals to mediate appropriate behavioural responses in the receiver. These chemical messengers have a two-way action – a releaser effect including such types of behaviour as alarm behaviour, trail following, aggregation, dispersion: and a triggering effect, kindling a chain of physiological events in the receiving organisms controlling such phenomena as caste determination.

Sex pheromones are so called because the compounds liberated by a female have a dual purpose of both attracting the male from a distance and also inciting it for mating, not to mention of substances produced by males to excite females. The extensive application of pesticides which has upset the delicate biological equilibrium of nature, has kindled interest in the behaviour modifying chemicals. Sex pheromones because of their ecofriendly, chemically safe and efficacious nature have found increasing favour in pest management with the passing years and are considered as the "fourth generation pesticides".

Researches over the last two decades have augmented the number of pheromones following their role in insect communication and behavioural control, and pheromones of over 500 species of Lepidoptera have been identified and properties such as volatility, persistence, and stability have their basis on molecular structure and it is well known that smaller the molecules the more volatile the components. Different isomers can evoke very different behavioural patterns in a responsive insect and hence the discrimination between these molecules must occur in the antennae and in the central nervous system.

Pheromones function as attractants and disruptants and an optimal blend must be identified and appropriate formulations for their release should be developed with current technologies. Information on orientation of flying insects is through the study of wind tunnels and sensitivity of compounds through the Electroantennogram or EAG technique, wherein the antennae of freshly incised males are used and two steel or glass microelectrodes are inserted into the antennae to record amplitude and frequency of nerve impulses from the sensory cells. The development of gas chromatography in the mid fifties provided an ideal tool for handling relatively volatile stable compounds and the subsequent coupling of gas chromatography with mass spectrometry (GC-MS) has enabled identification with even nanogram units of material and computers with chemical libraries enable comparison of the compounds.

Communication Modality

The receptivity of the males or behaviour releasing effect on the part of the males depend on the sensitivity of the antennae which play a great part in chemoreception. Insects can detect a few hundred molecules of their sex pheromone in the environment with their antennae, which contain several hundred thousand receptor cells. The antenna is a well designed sieve for airborne molecules which filter the female attractant substances out of the air. In each of the two male antennae there are about 1,700 olfactory hairs in the silk moths sensitive to the pheromone and each hair is innervated by two sense cells.

Once lodged in the antenna the odour molecule passes through many microscopic pores, each olfactory hair with around 2,600 of these pores. The molecules diffuse through the pores to the microscopic tubules beneath them, which extend very close to the sensory cells. The odour molecules require only about five thousandths of a second to diffuse from the surface of the antenna to the sense cells and result in the triggering of the nerve signal. After pheromone binding they are transferred to specific receptor sites followed by signal transduction.

Effectiveness of insect pheromones is proverbial, with only a few molecules needed to produce a response effective at considerable distances. Signalling power of insect sex pheromones is seen from the fact that molecular concentrations of 100 m/ml of air is sufficient for attraction of males. A single moth releasing its pheromone downwind from a particular site will produce an "active air space" several kilometres long and over a hundred metres wide. Any male entering the active air space will then turn up-wind towards the females. Single complex chemicals have been known to elicit behavioural responses at lower concentrations as in cockroaches. Many moth species utilise specific blends of relatively simple fatty acid derived compounds. A unique enzyme has allowed moth species to produce a variety of unsaturated acetates, aldehydes and alcohols that can be combined in almost unlimited blends to impart species specificity. Some strains within species use different ratios of individual components within a blend.

To take the simple example of the queen bee substance, the pheromone 9-keto-2-decenoic acid attracts male drones to mate with the queen. As many as 32 compounds are identified from bees and the related 9-hydroxy-2-decenoic acid causes clustering and destabilisation of worker swarms. Similarly though it was believed that the only female pheromone of the cabbage looper appeared to be (Z)-7-dodecenyl acetate, more intensive have studies shown five other minor components of the female gland.

Biosynthesis takes place in the pheromonal gland, the starting point being an acetate that is converted into palmitic acid. Several species also use directly performed acids such as oleic, linoleic and linolenic acids. Interestingly enough in many insects peak gland titers occur before the release period, decrease during the release period, rising again during the non release period. In some instances like the danaiid butterflies and bark beetles, the pheromones come from the diet. Pyrolizzidine alkaloids in the diet produce danaidone, which provides the receptive female the needed signal in the selection of mates.

Transfer of these toxic alkaloids to females occur during mating, the female in turn incorporating the alkaloids into her eggs, to prevent predation. It is again this chemical communication that orchestrates the destructive mass attack of bark beetles. Several corn silk volatiles including the plant hormone ethylene could induce pheromone production in the corn earworm. Signals from the host plant volatiles cause release of Pheromone Biosynthesis Activating Neuropeptides (PBAN), which stimulate pheromone production.

As such presence or absence of surrounding vegetation also influences production and release of pheromones. While diurnal rhythms occur in many moths, in many others a higher titer is maintained in the gland at all times, periodical release following periodical transport to the gland's surface. In the overall communication system two aspects – the chemistry of signal transduction and the frequency with which the pheromonal components interact with the receptor cells of the antennae are significant. This frequency depends on the release rate of the signal chemicals and the plume structure that carries them to the receiving insects.

One of the mechanisms of disruption is that the pheromone artificially placed in the field produces plumes and male moths encountering them may respond to them as if they are coming from females flying upward, thus reducing mating rate. The correct blend and the abundance of pheromone molecules in a fluctuating plume are essential aspects mediating up-wind flight to the odour source. The receiving insects become receptive to the sex pheromones at a specific time when the emitting insect is 'calling', the fluctuating plume structure being an integral part of the signal. While the chemical gradient does not exactly attract a male, the correct blend and the abundance of pheromone molecules in a fluctuating plume are effective in modifying flight up-wind, so that the patterning of the pheromones is as important as their composition.

Pheromones in Insect Control

As for the practical use of pheromones in insect control they are used in estimating populations and to know the time of peak incidence with traps being set up baited with the attached pheromone. Trap designs have to be tailored to the function required, and the behaviour of insects as they approach the traps, enter or escape from them is important. Enough traps for all of a local population or of one sex could be used to break their life cycle.

Mating disruption is an equally efficient control method like radio-jamming in which a powerful interfering signal is broadcast. Spreading an attractant pheromone throughout the crop area should impair the ability of the insects to locate prospective mates that are emitting the same pheromone. In typical field applications the disrupting pheromone is dispersed either aerially or from dispensers scattered throughout the crop area. As many other insects are also attracted directly to the dispensers, the mating disruption strategy has been modified through use of an insecticide to the pheromone creating an 'attracticide'.

Not only does the high level of the pheromone in the field interfere with mate location, but also many insects are killed outright at the dispensers. Equally interesting is the 'cocktail approach' in which several pheromones are put together in one device. In general, the mechanisms involved in mating disruption relate to loss of sensitivity, unbalanced components of pheromones and camouflaging of odour trail of females.

Worldwide, a variety of crops like cotton, rice, sugarcane, vegetables are treated with pheromones for pests like boll worms and leaf caterpillar of cotton, stem borers of rice and sugarcane, and bark beetles in forests, and phenomenal success has been achieved with the pink boll worm of cotton The pheromone traps have to be fixed at different levels as the crops grow, the traps attracting moths up to two weeks. Most of the commercially used pheromones in insect control strategies are mono or di unsaturated aliphtic compounds possessing alcohol, acetate or labile aldehyde functional groups.

Examples of pheromone mixtures of well-known Indian insect pests showing synergism enabling increased sexual responses are listed below.

Table

Insects	Pheromone mixture
Agrotis ipsilon:	(Z)-11-dodecenyl acetate & (Z)-9,tetradecenyl acetate
Chilo suppressalis:	(Z)-11-hexadecenal & (Z)-13-octodecenal
Helicoverpa armigera:	(Z)-11-hexadecenal & (Z)-9-hexadecenal
Pectinophora gossypiella:	(Z,Z)-7,11-hexadecadienyl acetate & (E,Z)-7,11-hexadecadienyl acetate
Phthorimaea operculella:	(E,Z)-4,7-tridecadienyl acetate & (E,Z,Z)-4,7,10-tridectrienyl acetate
Plutella xylostella:	(Z)-11-hexadecenal & (Z)-11-hexadecenyl acetate
Spodoptera litura:	(Z,E)-9,11-tetradecadienyl acetate & (Z,E)-9,12-tetradecadienyl acetate

The quantity and quality of pheromones released depend on the attributes of the dispensers or lures, which can affect the longevity of the pheromone, release rate over time and stability of the pheromone. These along with the shape of the plume, control the active space within which male moths are activated and attracted to the source. The blend emitted by the dispenser should be analysed, since different compounds may be released at different rates.

Though extreme specificity of pheromones may be disadvantageous when the crop has more than one pest, the use of a blend of chemicals can be useful. With the potential advantage of pheromones over more conventional pesticides for regulating insect pests, there is a need for increased research in this area, especially where insecticide resistance has developed. With better technologies and increased understanding of the biological effects of pheromone compounds, notably behavioural diversity in the field, prospects of the use of pheromones in integrated pest management are really promising.

◆ Chapter 85

Antifeedants or Feeding Deterrents

Many chemical compounds have been in use serving to prevent the feeding of phytophagous and other insects without killing or repelling them. These have been termed the feeding deterrents or antifeedants. Isman *et al.* (1996) have preferred a more restrictive definition—"a behaviour-modifying substance that deters feeding through a direct action on peripheral sensilla (= taste organs) in insects".

Most of the secondary metabolites produced by plants in nature are defensive chemicals that discourage herbivory, either by deterring feeding and oviposition or by impairing larval growth, rather than killing insects outright. Antifeedant properties are found in the major classes of secondary metabolites viz., alkaloids, phenolics and terpenoids, the last class offering the greater number and diversity of antifeedants.

Triterpenoids have been well documented as insect antifeedants: limonoids, exemplified by azadirachtin, from neem (*Azadirachta indica*) and chinaberry (*Melia azadirach*); toosendanin and limonin from *Citrus* spp.; cardenolides, steroidal saponins and withanolides. The clerodanes and the abietanes of diterpenes are also well known antifeedants. The drimanes and the sesquiterpene lactones of sesquiterpenes are also potent antifeedants and include such as drimane polygodial from the foliage of water pepper (*Polygonum hydropiper*). Application of polygodial or methyl salicylate has been reported to reduce aphid population in wheat and increase the yield. Monoterpenes, which are major constituents of many plant "essential oils", also deter insect feeding.

The furnocoumarins and the neolignans constitute the anitfeedants among plant phenolics. Similarly, certain indoles and the solanaceous gycoalkaloids among alkaloids exhibit antifeedant activity. Antifeedants have also been recognised from plants *Cocculus trilobus*, *Clerodendron trichotomum* and *Lindera triloba*. Some potent insect antifeedants isolated from plants are listed in the table below:

Table Antifeedants isolated from plants

Chemical type	*Compound*	*Plant source*
Alkaloid (indole type)	Strychnine	*Strychnos nuxvomica*
Alkaloid (steroidal glycoside)	Tomatine	*Lycopersicon esculentum*
Diterpene (abietane type)	Abietic acid	*Pinus* sp.
Diterpene (clerodane type)	Ajugarin I	*Ajuga remota*
Monoterpene	Thymol	*Thymus vulgaris*
Phenolic (benzoate ester)	Methyl salicylate	*Gaultheria procumbens*
Phenolic (furanocoumarins)	Xanthotoxin (= 8-methoxy psoralen)	*Pastinaca sativa*
Phenolic (lignan)	Podophyllotoxin	*Podophyllum peltatum*
Sesquiterpene (drimane type)	Polygodial	*Polygonum hydropiper*
Sesquiterpene lactone (germacranolide type)	Glaucolide A	*Vernonia* sp.
Triterpene (cardenolide type)	Digitoxin	*Digitalis purpurea*
Triterpene (ergostane type)	Withanolid E	*Withania somnifera*
Triterpene (spirostane type)	Aginosid	*Allium porrum*

Apart from plant secondary metabolites some synthetic pesticides have been reported to have insect antifeedant activities. Synthetic pyrethroids are known to deter feeding of insects when applied at doses or concentrations below the causing any mortality. Application of the fungicide Bordeaux mixture is also known to deter insect feeding.

Compounds like Eulan CN and Mitin FF were in use for protection of fabrics against insects and their larvae. Others like chlorinated triphenylmethanes and triphenylsulfonium salts were also used in the case of phytophagous insects. A triazene compound was noticed to inhibit the feeding of some caterpillars. In addition to triazenes, other compounds are known, like the organotins, which are triphenyltin compounds to possess pronounced antifeedant activities. Triphenyl acetate was found effective against the potato tuber moth larvae and larvae of cutworms but its use has not been favoured due to environmental concerns. Carbamates or carbonic acid esters, known to have efficient insecticidal properties, are also known to have antifeedant properties, in particular the thiocarbamates and phenylcarbamates, which inhibit feeding by beetles. Pymetrozine, a recently introduced chemical with an unique mode of action, has been reported to interfere with feeding in sucking insects like whiteflies and aphids by blocking salivary flow required by them, thus leading to starvation.

As to the modes of action of antifeedants, they act as gustatory repellents, inhibiting the gustatory or taste receptors, that in turn send signals to the feeding center in the insect's central nervous system. In some the antifeedants are thought to block or otherwise interfere with the perception of feeding stimulants. It is also to be noted that insect feeding comprises three essential aspects-orientation on the plants, initial biting or feeding and sustained feeding. While the first two aspects are common to insects feeding on both antifeedant-treated and untreated plants; sustained feeding is absent in antifeedant-treated plants.

The advantages of using antifeedants appear to be their selective action, which do not affect parasitoids, predators or pollinators. Their toxic deposits have no adverse effects on honeybees and other pollinating insects. However, they have their limitations, in that only surface feeding insects are prevented from feeding and internal feeders and piercing and sucking insects are not affected. Dosage also appears to be high, compared to insecticides. One additional advantage that has been pointed out in using antifeedants from plants, has been that insects may turn from crops to weeds.

The disadvantages are that continuous exposure or repeated exposures to the antifeedant may cause the insect to become increasingly tolerant. It has been reported that caterpillars can become habituated to a variety of plant secondary metabolites and may become cross-habituated i.e., exposure to one antifeedant can render the insect less responsive to the other. This can be mitigated by mixtures of antifeedants.

The potential use of antifeedants depends on more creative and practical strategies. One aspect is combining a plant extract having antifeedant activity with an insect growth regulator and applying it for crop protection. Another strategy is the SDDS i.e., Stimulo-deterrent diversionary strategy, sometimes also referred to as "push-pull" strategy of Miller and Cowles (1990). In this the "push" is from the antifeedant applied to the crop needing protection and the "pull" constitutes an attractant applied to the adjacent trap crop or trap rows of the main crop.

Isman, M.B., *Pesticide Outlook*, August, 2002, 152–157.

Isman, M.B. *et al.*, 1996. *Recent Advances in Phytochemistry*, **30:** 157–178.

Miller, J.R. and R.S. Cowles. 1990. *Journal of Chemical Ecology*, **16:** 3197–3212.

◆ Chapter 86

Insect Repellents

Insect repellents are chemicals causing insects to move away from their source and have been defined as "substances whose stimuli elicit avoiding reactions." They are not to be confused with antifeedants, since their action is to cause directed movements away from the source. They are typically behavioural responses arising through the stimulation of chemoreceptors, olfactory or gustatory receptors. Physical repellents are still used such as water barriers, tar or oil bands around tree trunks. Several chemical repellents, natural and synthetic are available today. Oil of citronella and oil of camphor are widely used as mosquito repellents. Spraying of Bordeaux mixture comprising copper sulphate and lime repels leaf hoppers and some chewing insects. Chemical treatment of logs keep them away from borer attack. Since the last world war several synthetic repellents have been discovered against body lice, mosquitoes, fleas, houseflies, ticks and chiggers. Of these dimethyl phthalate has proved effective in skin applications and benzyl benzoate and dibutyl phthalate for treatment of clothing. Diethyl toluamide is a product, which also provides protection against mosquitoes, ticks and fleas. Other cosmetically acceptable repellents in the form of cream or lotions are that of diethyl toluamide.

Buildings are protected against termites by the use of trichlorobenzene and similarly ants are repelled by ant tapes containing bichloride of mercury. Creosote and coal tar protect wood from termite attack and repel chinch bug migration. Butyl polypyrphene and dibutyl succinate are suitable repellents for application to live stock. Pyrethrum in low concentrations repels blood-sucking insects and are, therefore, used in cattle sprays. Application of pine tar oil and diphenylamine repels the screw worm flies from laying eggs around the wounds of animals. Recently effective compounds have been formulated for use against a wide range of insects attacking man and these compounds are related to cyano-acetic derivatives.

◆ Chapter 87

Sterility Methods of Pest Control

Inducing sexual sterility through the utilisation of radioactive isotopes, in large populations of insects, has been successfully employed in recent years in the control of some pests such as the screw worm in the USA, the oriental fruit-fly, and more recently mosquitoes. The procedure involves mass rearing, sterilisation and release of several thousands of males which compete against their own kind for reproduction. In course of time, after repeated releases, the sterile males would outnumber the normal males and the final outcome would be the disappearance of natural populations subjected to such treatment. The pioneering work of Knipling in this direction has led to effective control of the screw worm (*Cochliomyia hominivorax*), the melonfty (*Bactrocera cucurbitae*), the Oriental fruitfly (*B. dorsalis*), the Mediterranean fruit fly (*Ceratitis capitata*), etc. Introduction of fully competitive sterile individuals in a population reduces the reproductive potential of the natural populations. Initially, however, only males were sterilised to eradicate isolated population, but subsequently the sterilisation of a given proportion of both sexes of the natural population was found to be equally useful. Sterilisation of 90 % of an insect population has been estimated to reduce the reproductive capacity of the remaining 10 % by 90 %, leaving only 1 % to reproduce, the net result being the suppression of their reproductive capacity by 99 %.

The sensitivity of insects to radiation is low when compared to that of vertebrates and it also varies with the age of the insect. Quite a few differences exist between the sterilising dose and the lethal dose for the different postembryonic stages of insects. This radioresistance of insects has been attributed to the meagre cell division and differentiation of tissues occurring in the larval life, where growth takes place through increase in cell volume without a corresponding increase in cell numbers. Since the mitosis is seen in the pupal stage, this stage is radiosensitive, and in the adult the cells of the gonad divide which are sensitive to radiation. Here even low doses result in sterilisation, without damaging other tissues. The sterility dose for a medium-sized insect is about 5,000 to 8,000 and the lethal dose 200,000r.

Insects are irradiated by exposure to Cobalt 69 irradiation, where large populations could be handled. Radioactive isotopes are also applied on insects by spraying the insects with a solution on a particular area of the body or by feeding the insects on diets containing the isotope. This method also serves in the identification of the treated insects by their radioactivity. The common radioactive isotopes used for labelling studies with insects are carbon 14, phosphorus 32, iodine 131, bromine 82, arsenic 76, sulphur 35, etc.

When the extension of sterility techniques to other insects is considered, several aspects have to be looked into, especially the effect on survival and reproductive behaviour, methods to be adopted for rearing and proper methods of dispersal of released sterile insects so that they could mix with natural populations. Further, the sterile insects should also not cause undue loss to crops and livestock. Through repeated release of sterile males, the ratio of sterile males to normal males becomes increased.

Sterility method has been employed more recently in fighting the gypsy moth, codling moth, cotton bollworm and weevil, *Anopheles* sp., and it seems that the technique will attract more attention.

◆ Chapter 88

Plant Quarantine

The term 'Quarantine' is derived from the latin word '*quarantum*' meaning forty. It was originally applied to the period of detention of ships arriving from countries where epidemics like bubonic plague, cholera and yellow fever occur. The passengers and crew were to remain isolated on board giving enough time to permit latent cases of diseases to develop. When compared to human quarantine , plant quarantine is a later development. The first Plant Quarantine legislation in the world was enacted in the Netherlands. East Indies (Indonesia) in 1877 prohibiting the importation of coffee plants and seeds from Sri Lanka. India adopted plant quarantine measures in 1914 by introducing the Destructive Insects and Pests Act. This was later supplemented by a more comprehensive statute in 1917.

Plant quarantine is a legislative measure to prevent or to exclude from a defined geographical area a serious pest or disease of plants exotic to that particular geographical area.

In order to improve agricultural production or to supplement the food needs, plants, plant material and plant products are in continuous transport from one region to another. Germplasm banks have been established for important crops in different parts of the world. Exchange of germplasm material among nations has become a regular feature.

Some of the flora and fauna are specific to certain geographic regions. When man moves plants, seeds, timber or even goods, he is also likely to move an insect or fungus from its native habitat. Such an introduced pest may behave entirely different from its native habitat. Freed from its natural enemies and competitors and with availability of possible susceptible host/s in its new environment, the pest species may have more serious effects than in its place of origin. Consequently, in order to prevent such introduction and safeguard agriculture, horticulture, forestry, and human and animal health, Governments have come up with legislative measures.

There are instances in Indian history to show that some introduced pests were disastrous. The coffee berry borer *Hypothenemus hampei,* the San Jose scale *Quadraspidiotus perniciosus,* the apple woolly aphis *Erisoma lanigera,* and the Spiralling whitefly *Aleurodicus dispersus* are some examples.

In India two categories of regulatory measures are in operation to prevent entry of foreign pests and to prevent spread of already established pests. They are:

- Legislative measures through Plant Quarantine, and
- Legislative measures through State Agricultural Pests and Diseases Act.
- In the first category, regulatory measures are aimed at preventing the introduction of exotic pests and diseases into the country from abroad or their spread from one State or Union Territory to another; while the second pertains to suppression or prevention of spread of pests and diseases in localised areas within a State or Union Territory.

In line with other countries, India has also developed facilities for plant quarantine inspection and treatments at the seaports of Mumbai, Kolkatta, Kochi, Chennai, Tuticorin, Rameswaram, Bhavnagar and Vishakapatnam, and at the airports of Amritsar, Chennai, Kolkatta, Mumbai, New Delhi and Tiruchirapalli. The land-frontiers are Attari-Wagah border, Amritsar district and Bongaon, Gade Road, Kalimpong and Sukhiapokri in West Bengal. These stations operate under the Government of India's Destructive Insects and Pests Act, 1914. The importation of consignments of plants from foreign countries has to be done only through any of these ports. The consignments should be accompanied by certificates issued by the authorities of the exporting country as to their freedom from pests and diseases; these certificates are called phytosanitary certificates. At the port of entry these consignments are inspected, and if necessary, fumigated to kill the pests carried by them. Detention of consignments is ordered if found infested/infected with a quarantine pest or imported in contravention with plant quarantine regulations, for arranging deportation, failing which the consignments shall be destroyed at the cost of the importer.

In a similar way, all exports of commodities such as pepper, tamarind, cardamom, mango, tissue culture plant material, flowers, etc. are required to have phytosanitary certificates accompanied with the consignments.

The Directorate of Plant Protection, Quarantine and Storage was established in 1946. Prior to this the enforcement of quarantine laws and disinfestations of plants as laid down in the Act was done by customs authorities. From 1949 the Directorate has established quarantine stations in a number of ports and airports and land frontiers, and is in charge of these activities.

In the case of importation of natural enemies from other countries into India for being used in the biological control of weeds, prior permission to import such natural enemies is granted by the Plant Protection Adviser to the Government of India and quarantined at the Project Directorate of Biological Control, Bangalore and evaluated. After it is satisfactorily established that the introduced species is not likely to become a pest species, further developments in the fields and other laboratories are taken up. When live insects are sent abroad, a no objection certificate that the species is not covered under endangered species must be obtained for clearance for export. Further a no objection certificate from the importing country should also be annexed to the consignment to meet the quarantine requirements of the importing country.

Section Ten

Toxicology

◆ Chapter 89

Insecticides and Their Classification

The term ***pesticide*** is used to denote those chemicals, which poison and control the animal and plant species. Many chemicals are used for reducing the population of insects or for preventing their attack. Chemicals, which kill insects by their chemical action, are called insecticides. ***Insecticide*** is thus defined "as a substance or mixture of substances intended for killing, repelling or otherwise preventing insects." Likewise chemical substances applied to kill nematodes, mites, rats and molluscs are referred to respectively, as nematicides, acaricides, rodenticides and molluscicides. A chemical may be called a repellent if it prevents the pest species from attacking its host and an attractant if the pest species is attracted to the source, trapped and killed. If the chemical applied inhibits feeding it is called an antifeedant. Chemicals, which induce sterility are grouped as chemosterilants. Biorational pesticides are those which include pest control agents and chemical analogues of naturally occurring biochemicals, viruses, bacteria, protozoans and fungi, and thus distinct from chemical pesticides.

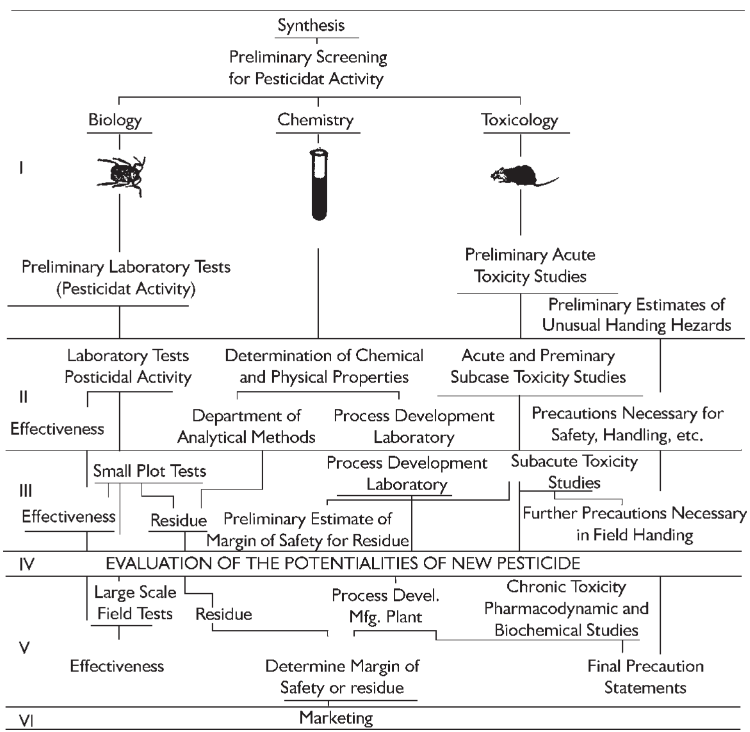
I. HISTORICAL BACKGROUND OF THE USE OF PESTICIDES

Insecticides were in use from very early times and as early as 200 BC boiling a mixture of bitumen (mineral pitch or asphalt) and blowing the fumes through grape leaves was advocated to keep away the insects. Sulphur was considered to be injurious to insects in 100 BC. The toxic nature of arsenic was known about 40 to 90 AD and arsenic sulphide was used by the Chinese before 900 AD. Arsenic in honey was suggested as an ant bait since 1669. The use of tobacco in the control of the lace bug on pear trees was in vogue in 1690. Pyrethrum was widely used before 1800 in Persia.

The use of modern insecticides commenced in 1867 with the application of Paris Green for the control of the Colorado beetle. Mostly organic chemicals and a few plant products were in use until 1939 when the whole concept of insecticides and of insect control was revolutionised with the discovery of the insecticidal spectrum of DDT. Since then a large number of compounds have been synthesised, examined for their insecticidal activities and developed. In 1941-42 the insecticidal properties of HCH were discovered by British and French investigators. During the same period the potential of phosphorus chemicals were investigated by the Germans, which led to the development of parathion, malathion, demeton, TEPP, etc. Since then phenomenal progress has been made in the development of insecticides, as a result of which insecticides have now been found among organophosphates, carbamates and other new classes of compounds.

II. PESTICIDE RESEARCH AND DEVELOPMENT

About 20 large companies in Western Europe and the USA are actively engaged in basic discovery, development, evaluation and manufacture of modern pesticides. The six stages involved in the development of a new pesticide from synthesis to marketing are illustrated in Fig. 88.1.



▲ **Fig. 89.1** *The six stages in the development of a new pesticide*

Primary screening, determination of general biological characteristics, analytical and metabolic studies, basic and applied toxicology, chemical synthesis, formulation studies, etc. are undertaken in a single location and duplication of such investigations in some other locations is unnecessary. On the other hand the evaluation of biological performance and assessment of possible hazards under the intended conditions of use require to be studied in different locations, which may involve investigations against locally important pests and under local climatic and agricultural conditions. The basic chemical discoverer, by his own network of centres in different countries or in cooperation with other distributing companies, carries out extensive field investigations as part of the development work. The success of a compound largely depends on its safety, efficacy and profitability to the user.

It takes about five or occasionally more years for the development of a compound and it has been estimated that around one in 360,000 of the compounds become a major commercially successful new pesticide. Around six to ten million US dollars are spent in the development of a major new insecticide and this brings out the high expenditure involved on research and development of a pesticide.

III. INSECTICIDE FORMULATIONS

It is essential that the toxicant must be amenable to application in an effective manner so as to come into direct contact with the pest or leave an uniform and persistent deposit upon the plant surface. Only a small quantity of the toxicant is required to be distributed over a large area and very rarely the toxicant in a concentrated form, suitable for direct application, is formulated. The toxicant is to be made available in a diluted form or in a form easily distributed. Therefore, the compound containing the toxicant must be formulated in a form suitable for use as a spray, dust or fumigant. The common formulations of pesticides are detailed hereunder.

1. DUSTS

In a dust formulation the toxicant is diluted either by mixing with or by impregnation on a suitable finely divided carrier. The carrier may be an organic flour (Walnut-shell flour, wood bark) or pulverised mineral (sulphur, diatomite, tripolite, lime, gypsum, talc, pyrophyllite) or clay (attapulgite, bentonites, kaolins, volcanic ash). The toxicant in a dust formulation ranges from 0.65 to 25 %. Dusts are defined as those having a particle size less than 100 microns and with decrease in particle size the toxicity of the formulation increases. The properties of the diluents employed mainly decide the quality of the finished dust formulation and the rate of decomposition is influenced by the kind of diluents. Some formulations are inactivated by alkali. In the selection of a dust formulation its compatibility, fineness, bulk density, flux, abrasiveness, absorbability, specific gravity, and cost must be borne in mind. The dust should flow freely and must not cake or ball in the hopper. It has been reported that in field application deposition had been more on the undersurface of leaves and in those held parallel to the air-stream carrying the dust. Dust application must be done in calm weather conditions and early in the morning when the plant is wet with dew.

2. GRANULAR OR PELLETED INSECTICIDES

In a granular formulation the particle is composed of a base such as an inert material or vegetable carrier impregnated or fused with the toxicant, which is released from the formulation in its intact form or as it disintegrates giving controlled release. The particles in the formulations generally possess a size range of 0.25 mm to 2.38 mm diameter but usually 250 to 1250 microns. Those having a range of 100 to 300 microns are referred to as a microgranules, and those above 300 microns as granules. The formulations contain two to ten per cent concentration of the toxicant. This type of formulations finds use in the control of weeds, plant diseases and insect pests, nematodes, snails, rodents, etc. Granules are prepared in three ways:

(i) Spray impregnation technique in which a solution of the toxicant or, if liquid, the toxicant itself is sprayed on to preformed absorptive granules.

(ii) Agglomeration technique in which the toxicant and powdered filler, together with any other additives, are moistened with water or other suitable liquid and formed into granule and dried. In this method, there is considerable degree of control over the release of the toxicant.

(iii) Stick-on technique in which the toxicant is applied as a thick, viscous slurry so as to stick to the outside of the impregnable granular base such as sand. Adsorptive clay is then added to the formulation or it is dried to remove any surplus liquid and prevent the finished granules from sticking together. This method allows least control over the release of the toxicant.

The granules are applied over standing water or whorls of plants or to soil. In the water the toxicant from the granule is released to act in three ways: by vapour, by systemic action through plant roots, and systemically in the leaves and stem. When applied on the soil or incorporated into it by tilling or by drilling or by hand there is increased retention. When applied to foliage retention of the granule in leaf axils and its breakdown assisted by moisture are important. The toxicant and granule particles are picked up directly by mobile insects and systemic toxicants enter the plant.

The performance of granules is dependent on uniformity of distribution, weather factors particularly duration and intensity of rainfall and temperature, concentration, dosage rate of the toxicant, etc. Granular formulations of systemic insecticides are used for the control of sucking and soil pests by application to the soil. Whorl application is done for the control of borer pests of crops such as sorghum, maize, sugarcane etc.

The stability of *Bacillus thuringiensis israelensis,* if not protected in a suitable formulation, is considerably restricted as a result of UV light action and biological degradation. A new time release granular formulation has been developed providing more sustained release and increased UV protection of the active ingredient.

Advantages of granules are:

(i) There is very little drift,

(ii) There is no undue loss of insecticide,

(iii) Undesirable contamination is prevented,

(iv) Residue problem is considerably less as granules do not adhere to plant surface,

(v) Release of toxic material is achieved over a longer period than does a spray deposit,

(vi) Water is not required for application.

(vii) Less harmful to natural enemies of the pest species,

(viii) Ready to use; no mixing, is required

(ix) Low hazard to applicator.

Disadvantages of granules are:

(i) Not as effective as sprays against most crawling insects,

(ii) Scorching may occur if the toxicant is concentrated in a smaller volume of carrier,

(iii) Won't adhere to foliage,

(iv) More expensive than WPs and ECs.

(v) May need to be incorporated into soil in some cases,

(vi) May need moisture to activate pesticidal action.

3. WETTABLE POWDER (WP) OR WATER DISPERSIBLE POWDER (WDP)

It is a powder formulation, which yields a rather stable suspension when diluted with water. The active ingredient in such a formulation ranges from 15 to 95 per cent. It is formulated by blending the toxicant with a diluent such as attapulgite, a surface-active agent and an auxiliary material (such as sodium salts of sulfo acids obtained by sulfonation of petroleum products, sodium salts of lignin sulfo acids). Sometimes stickers are added to improve retention on plants and other surfaces. Though the particles of a suspension adhere well to treated surfaces they do not penetrate and thus are easily washed off. However, suspensions are usually more effective than dusts. The requirements for a water dispersible powder formulation are:

(a) Stability in storage and absence of caking;

(b) Quick formation of suspension and slow settling out of solid particles;

(c) Good moisture retention capacity and ability to spread over treated surface: and

(d) Retention on treated surface for a longer period.

4. WATER SOLUBLE POWDER (SP OR WSP)

The water soluble powders contain an active ingredient in the form of surfactants with special additives. It is a powder formulation readily soluble in water. Addition of surfactants improves the wetting power of the spray fluid. Sometimes an anti-caking agent is added, which prevents formation of lumps in storage. This formulation usually contains a high concentration of active ingredient and, is therefore, convenient to store and transport. Carbaryl 85 SP and Acephate 75 SP are registered in India.

5. LIQUIDS

Many of the synthetic organic insecticides are water insoluble but soluble in organic solvents such as amyl acetate, carbon tetrachloride, ethylene dichloride, kerosene, xylene, petroleum naphtha, pine oil, etc. which themselves possess some insecticidal properties of their own. Solvency, toxicity to plants, fire hazard, compatibility, odour and cost are factors to be considered in the selection of a suitable solvent. Some toxicants are dissolved in an organic solvent and used directly for control of household pests and other aquatic insects especially mosquitoes.

5.1 Emulsifiable Concentrate (EC)

The formulation contains the toxicant, a solvent for the toxicant and an emulsifying agent. It is a clear solution and yields an emulsion of oil-in-water type when diluted with water to spray strength. When sprayed the solvent evaporates quickly leaving a deposit of toxicant from which water also evaporates. Some of the emulsifying agents in insecticide formulations are alkaline soaps, organic amines, sulfates of long-chain alcohols, sulfonated aliphatic esters and amides, and materials such as alginates, carbohydrates, gums, lipids, proteins and saponins. The addition of emulsifying agents have the following specific purposes in insecticidal formulations:

(i) Diluting of a water insoluble chemical with water is made possible;

(ii) The surface tension of the spray is reduced allowing it to spread and wet the treated surface;

(iii) A better contact with insect cuticle is made possible;

(iv) Droplet size of the emulsion is greatly influenced by the kind and amount of emulsifier used;

(v) The chemical structure of the emulsifier has influence on the stability and behaviour of the emulsion. Emulsions are not stable and tend to separate into component parts and this is referred to as "breaking". The amount of emulsifier and agitation applied to the emulsion control this phenomenon to some extent. A fairly quick-breaking emulsion is preferred in crop spraying in view of heavier deposits of toxicant obtainable probably due to limited run off. An emulsion may separate into two phases due to differences in specific gravity of the components and this partial separation of the emulsion known as "creaming". The emulsion can be returned to homogenous condition by slight agitation.

5.2 Suspension Concentrate or Flowable (F)

The suspension concentrate consists of an active ingredient, water, surfactants(wetting agents, dispersing agents), special additives and carrier. When an active ingredient is insoluble in either water or organic solvents, a flowable formulation (F) is developed. The active ingredient is milled with a solid carrier (e.g. inert clay) and subsequently dispersed in a small quantity of water. It can easily be measured and poured and hence easy to handle. Prior to application it has to be diluted with water. Flowables may show sedimentation of the solid materials in storage and agitation by stirring or shaking makes the sediment redispersed. A flowable formulation of carbaryl was considered safer to honeybees and exhibited rain fastness.

5.3 Solution Concentrate (SC)

The solution concentrate of active ingredient, water immiscible solvent and surfactants. This liquid formulation contains the active ingredient in a water miscible solvent. When mixed with water during spraying the solvent dissolves in water leaving the a.i. (active ingredients) alone. Addition of a surfactant provides wetting power. Example: monocrotophos.

5.4 Concentrate Insecticide Liquids

The technical grade of the toxicant at a high concentration is dissolved in non-volatile solvents. A more volatile solvent is also added to enable solution and drop formation. An emulsifier is not added. The solvent used should not be phytotoxic. Concentrate insecticide liquids should be non-volatile, and have a high viscocity and high specific gravity (over 1.3 g/ml). This condition enables it to be applied from higher altitudes in extremely fine droplets without being diluted with water and at ultra volume rates. There is greater residual toxicity and less loss through evaporation on application and extensive coverage is achieved. Concentrate liquid formulations of malathion and fenitrothion have been permitted to be used in India.

6. MICROENCAPSULATION

Microencapsulation process involves particles of a pesticide, either liquid or dry, surrounded by a plastic coating. This is mixed with water and applied as a spray. Encapsulation makes timed release possible.

7. AEROSOLS

In insecticide aerosol the toxicant is suspended as minute particles (of size ranging from 0.1 to 50 microns) in air as a fog or mist. This is achieved by burning the toxicant or vapourising it with heat or atomising mechanically. The toxicant dissolved in a liquefied gas, if released through a small hole, may cause the toxicant particles to float in air with the rapid evaporation of the released gas.

8. TABLET

Deltamethrin has been formulated in the form of tablet, which readily dissolves in water; when a tablet is mixed with 20 litres water to cover 400 sq. m. crop area it gives 12.5 g a.i./ha dosage. Aluminium phosphide, magnesium phosphide and boric acid are also formulated in tablet forms.

9. PLATE/STRIPS

The fumigant Magnesium phosphide is available in the form of strips or plates.

10. MIXTURES OF ACTIVE SUBSTANCES OR PRE-MIXES OR COMBINATION PRODUCTS

It becomes necessary often to apply mixtures of active substances of insecticides for obtaining effective control of the pest complex in a crop. The following four types of action for mixtures of active substances are recognised.

(a) Similar action: The two components in a mixture act independently but produce similar effects whether they are applied as a mixture or alone. For example, one may have quick acting property and another residual toxicity.

(b) Independent action: The two components are different and independent in action i.e. no synergistic effect. For example, parathion methyl and 1% sesamex, a pyrethrum synergist against housefly.

(c) Synergistic action: The toxicity of the mixture is greater than that of the sum of the individual components. This phenomenon is referred to as synergism or activation. For example, 1% of the pyrethrum synergist sesamex acts synergistically with phosphates containing amino or amido groups. Piperonyl butoxide, piperonyl cyclonene, N-isobutyl undecylenamide, propyl isome, sesoxane, etc. are some insecticide synergists.

(d) Antagonistic action: One component in a mixture reduces the activity of the other in the mixture. For example, due to antagonistic action the toxicity of thionophosphates is diminished by sesamex; antagonistic action between aldrin and parathion. Combination products or pre-mixes are products constituted by mixing two or more compatible pesticide molecules in the right concentration. This concept in not very novel as farmers have been mixing pesticide in a tank i.e. tank mix before application. Where as individual components of the combination are effective only against specific pests, pre-mixes are effective over a broad spectrum of pests. The pre-mix is formulated under controlled conditions and the constituents are decided so as to attain synergy out of their joint action. The compatibility of the constituents is gauged and the effect of the cross-interaction of various auxiliaries is analyzed for any hazardous side effects. It is feared that if any pest species develops any resistance against any mixture then the resistance problem will be more cumbersome because of cross-resistance.

The following combination products have been registered for use in India: Cypermethrin 50 g + chlorpyrifos 500 g/ litre, Cypermethrin 40 g + profenofos 400 g/ litre, Cypermethrin 30 g + quinalphos 200 g/litre, Carbaryl 40 g + gamma HCH 40 g/kg granule, Cyperme-thrin 50 g + chlorpyrifos 500 g / litre, Cypermethrin 50 g + ethion 400 g / litre, Deltame-thrin 10 g + triazophos 450 g / litre, and Alphacypermethrin 10 g + chlorpyrifos 160 g / litre.

The advantages of mixtures of active substances of insecticides are:

(i) Effective pest control as well as reduction in cost of control operation is achieved,

(ii) Development of resistance in insects to insecticides may be prevented due to independent action of the active substances in the mixtures,

(iii) It is also possible to control resistant strains of insects.

11. POISON BAITS

The poison baits consist of a base or carrier material attractive to the pest species and a photogenous or chemical toxicant in relatively small quantities. The poison baits are used for the control of fruit-flies, chewing insects, wire-worms and white grubs in the soil, household pests, and slugs. This method is ideal under conditions where spray application is rather difficult. The common base used in dry baits is wheat bran moistened with water and molasses as an attractant, and a toxicant such as parathion, sodium arsenite, etc., is added. Ground corn cobs, hulls of seeds, saw dust, horse droppings etc. are also used as base. Amyl acetate, chopped whole orange or other fruits, etc., are also used as attractants. Such baits are adopted for the control of locusts, grasshoppers, cutworms, armyworms, cockroaches, crickets, earwigs, silverfish, etc. Poison baits in liquid bases are used for control of fruit-flies, fruit-piercing moths, houseflies, ants, etc. The baits for fruit-flies usually consist of methyl eugenol + DDVP or malathion with corn protein or yeast hydrolysate. For the control of fruit-piercing moths fermenting sugar solution or molasses with a toxicant is used. Cockroaches and houseflies are killed by the use of baits containing a toxicant, attractants and auxiliaries. For successful poison baiting the attractivity, palatibility, toxicity, stability and physical condition of the baits as also the time, place and method of exposure must be considered. Difficulty in achieving an uniform spread of the bait throughout the crop, high cost of the attractants, and non-persistence for a longer period are some limiting factors in successful poison baiting in pest control.

12. FUMIGANTS

A chemical compound, which is volatile at ordinary temperatures and sufficiently toxic, is known as a fumigant. Fumigants are used for the control of insect pests in storage bins, buildings and ship holds, and certain insects and nematodes in the soil. It is practicable under situations where the gas can be confined. Most fumigants are liquids held in cans or tanks and quite often they are mixtures of two or more gases. Phosphine or hydrogen phosphide gas is generated in the presence of moisture from a tablet/strip/plate consisting of aluminium or magnesium phosphide and ammonium carbamate. Sometimes the gas is required to be produced at the site of fumigation as in hydrogen cyanide, which is by dropping calcium cyanide into earthenware crocks filled with sulphuric acid. The advantage of using a fumigant is that the places not easily accessible to other chemicals can be easily reached due to the penetration and dispersal effect of the gas. However, the fumigants should be handled with utmost care as the gas may prove to be toxic or may cause flavours in the treated crop.

13. SPECIAL FORMULATIONS

These are prepared for specific purposes. In oral administration of insecticides in animals they are prepared as boluses (large pills) or capsules with a balling gum. In the treatment of pet animals in houses the insecticide may be mixed in shampoos. Sometimes an insecticide may be mixed with wax and applied on floors. Extremely toxic systemic insecticides are prepared at the factory in gelatine capsules. When gelatine gradually breaks down in the soil toxicant enters the soil and gets absorbed by the plant roots.

14. INSECTICIDE-FERTILIZER MIXTURE

The mixtures generally constitute addition of a granular insecticide to chemical fertiliser or spreading of insecticide directly on to the fertiliser. They are applied at the regular fertilizing time and provide both plant nutrients and control of soil insects. Urea 2% solution is mixed with compatible insecticidal emulsions and sprayed for supply of nitrogen to the plant and for realising effective pest control. Many pesticides are rapidly broken down when mixed with fertilisers.

15. ADJUVANTS IN INSECTICIDE FORMULATIONS

Deodorants and Masking Agents

Addition of pine oil, flower scent, etc. at 0.1 to 1.0 % concentration to finished products of insecticides is done to mask the unpleasant odours of insecticidal components such as pyrethrins, thiocyanates and methylated naphthalenes.

Stabilising Agents

These are added to relatively unstable organic insecticides to retard decomposition in storage. Decomposition of pyrethrin in louse powder is prevented by mixing of an antioxidant mixed isopropyl cresols. Epichlorohydrin, an acid inhibitor, prevents the dehydrochlorination of aldrin and toxaphene formulations. Organochlorine insecticides are stored in metal drums provided with special interior lacquer linings to prevent decomposition.

Spreaders

These are auxiliary spray materials, which directly facilitate contact between spray (liquid) and sprayed (solid) surfaces. The spreader in insecticidal formulations has three important functions viz. wetting, spreading and penetrating effects. Soaps, alkyl sulphates or sulphated alcohols are available under different trade names. Secondary alcohol sulphates from petroleum oil refinement such as Teepol, Tergitols, etc., fatty acid detergents such as Mersolates, etc., Triton X-100, Tweens, and a few other non-synthetic products such as saponins from wide variety of plants, particularly from the bark of *Quillaja saponaria* and the pericarp of the fruit of *Sapindus utilis*, are some spray spreaders.

Stickers in Insecticides

The adhesiveness of certain formulations of insecticides, such as emulsions and wettable powders, is improved by addition of stickers or supplementary adhesive materials like various clays and bentonites, soybean flour, casein, gelatin, petroleum and vegetable oils, blood albumin, etc.

16. WATER-SOLUBLE PACKET

It is used to reduce the mixing and handling hazards of some highly toxic pesticides. Known quantity of wettable/soluble powder formulation is packaged in water-soluble plastic bags. When the bag is dropped into a filled spray tank it dissolves and releases the content to mix with the water. There is no risk of inhaling or coming into contact with the undiluted pesticide during mixing as long as the packet is not opened.

IV. CLASSIFICATION OF INSECTICIDES

Insecticides may be classified in several ways based on the mode of entry, mode of action, and the chemical nature of the toxicant or active ingredient.

1. CLASSIFICATION BASED ON MODE OF ENTRY

Based on the manner in which toxicants arc administered to the insects and their mode of entry into the body, the insecticides are classified into three groups–stomach poison, contact poison and fumigant.

Stomach Poison

These include those toxicants applied to the food. When ingested by the insect, the insecticide kills primarily by action on or absorption from the digestive system. Though usually it is limited to the control of insects with chewing mouthparts, under certain conditions it may also find use in controlling insects with sucking, siphoning, sponging or lapping type of mouthparts.

The possible ways of ingestion of the stomach poisons are:

(i) The insect while feeding on its natural food, such as foliage, feathers of birds, etc., covered thoroughly with the toxicant, ingests the poison also;

(ii) By feeding on poison baits consisting of the toxicant and an attractant in a suitable food material;

(iii) The toxicant sprinkled on runways is picked by the antennae and legs of the insect and it is likely to ingest the poison while cleaning these appendages with its mouthparts; and

(iv) Sucking insects, while feeding on plants treated with systemic insecticide, suck the plant sap containing the toxicant, which acts as a stomach poison in the insect.

A stomach poison should be sufficiently stable, cheap and available in larger quantities and should not be distasteful as to repel the insect. It should be able to kill the pest quickly. The chemical should not be soluble in water and phytotoxic to plants, it should have finer particles and spread uniformly and adhere well to the treated surface, it should not leave any harmful residue on the treated surface.

Contact Poison

A toxicant, which kills the insect by contact and whose entry into the body is through the vulnerable sites found on the body of insect is said to be a contact poison. It may be applied directly on to the body of the insect as spray or dust. On the other hand if application is made so as to leave a residue of the toxicant on plant surfaces, animals, habitations, etc. frequented by insects, the toxicant is likely to be picked up by the insect when it comes in contact while crawling or passing over the treated area. This type of poison is particularly effective for the control of sucking insects.

When applied, the toxicant spreads quickly over the entire surface of the body of the insect, possibly in the wax monolayer and apparently from there, the poison gets absorbed on to the surface of the cuticle. It penetrates into the body of the insect through sutures, membranes, bases of setae and possibly other portals of entry. Though it was widely held that the insecticide penetrates through the integument of the body wall and gets carried to the target organ, the central nervous system by the haemolymph, investigations have shown that the toxicant does not penetrate into the haemolymph in significant amounts and reaches the site of action via the integument of the tracheal system.

Contact insecticides are found in:

(a) toxicants of plant origin such as rotenone, nicotine, anabasine, ryania, sabadilla and pyrethrum:

(b) synthetic organic compounds such as organochlorines, organic thiocyanates, organophosphates, carbamates, nitrophenols, etc.;

(c) oils and soaps and

(d) inorganic compounds such as lime-sulphur and sulphur, and arsenic trioxide and sodium flouride to a limited extent.

Many contact insecticides at higher dosage levels may prove to be phytotoxic on plants.

Fumigant

A toxicant which is applied as a vapour, enters the tracheae of the insect through the spiracles in the form of gas and kills the insects; such gaseous toxicant is called a fumigant. Fumigants finds use in the control of all kinds of insects irrespective of the type of mouthparts they possess. Their application is limited to plants or products in air-tight enclosures, tents or buildings or to soil. A fumigant, which generally boils at about room temperature is the most useful one and such chemicals include methyl bromide, hydrogen cyanide and ethylene oxide. The essential requirement of a soil fumigant is slower release of vapour from chemicals boiling at a temperature as high as 180°C. Fumigant action is evidenced when naphthalene and paradichlorobenzene having relatively high vapour pressure are used in tight containers, and also in certain contact insecticides like DDVP, lindane, etc. An ideal fumigant is determined by its relative effectiveness, cost, safety to human beings, animals and plants, inflammability, penetrating power, effect on germination of seeds, reactivity with household furnishings, etc.

2. CLASSIFICATION BASED ON MODE OF ACTION

Based on the ways in which the chemicals act upon the system of an insect to cause its death, insecticides may be classified as follows:

Physical Poison

A physical poison exerts a physical rather than a biochemical effect and brings about destruction of insects by asphyxial (exclusion of air) effect as with heavy oils and tar oils, or by effecting a loss of body moisture from the insect by inert dusts. Epicuticle of the insect gets lacerated by abrasive dusts like aluminium oxide, flyash etc., and this may cause water loss. Water absorbent materials like charcoal remove water. Certain dusts may combine both the characteristics.

Protoplasmic Poison

A protoplasmic poison is primarily associated with precipitation of protein. The cellular protoplasm of midgut epithelium is destroyed by inorganic stomach poisons like fluorides, arsenites, arsenates, fluosilicates, fluoaluminates and borates, alkaloid reagents nitrophenols and nitrocresols, fatty and mineral acids, formaldehyde, and ethylene oxide and heavy metals like mercury and copper.

Respiratory Poison

A respiratory poison is associated with blocking of cellular respiration and inactivation of respiratory enzymes as is the case with fumigants like HCN, H_2S and CO (carbon monoxide).

Nerve Poison

The action is primarily associated with the solubility of the toxicant in tissue lipoids and inhibition of acetylcholinesterase in insects and warm-blooded animals.

A chemical substance acctylcholine is formed in the nervous system of insects and mammals mediating in the conduction of the nervous impulses over the microscopic gap between nerves or between nerve and gland or muscle. Acetylcholine, after it has served its function, is destroyed by an enzyme, acetylcholinesterase present in the tissues so that the end-organ (nerve, gland or muscle) may return to its resting state preparatory to repeating its function. If acetylcholine is not destroyed by acetylcholinesterase, it will continue to cause impulses to move along the nerve and cause increased excitation, which induces the production of a new coactive substance by the central nervous system. When produced in large quantities, this natural substance becomes a toxicant and disrupts the normal nerve functions resulting in tremors, convulsions, muscle paralysis and finally death.

Acetylcholine is hydrolysed by the enzyme acetylcholinesterase to form a choline and an acetate-enzyme, the latter reacts instantaneously with water and splits into acetic acid and free enzyme. When required the enzyme is again used to hydrolyse more acetylcholine whereas the acetic acid and choline are used in other physiological processes.

Organic insecticides are active inhibitors of acetylcholinesterase enzyme in insects and mammals. The nerve poisons include the organochlorine compounds (DDT, lindane, paradichlorobenzene, carbon tetrachloride, ethylene dichloride), aromatic and olefinic hydrocarbons (kerosene, gasolene, naphthalene), botanic insecticides (pyrethrine, nicotine), organic phosphates (parathion), *N*-methyl carbamates and miscellaneous chemicals like aniline and carbon disulphide. DDT does not inhibit cholinesterase but initiates high nervous excitation. In the case of poisoning with organophosphatic compounds the phosphorylated enzyme is irreversibly inhibited. On the other hand carbamates are irreversible chlorinesterase inhibitors.

Poisons of a More General Nature or Action

Aldrin, chlordane, dieldrin and toxaphene do not induce neurotoxic symptoms until a latent period has passed. An immediate depressant action is noticeable in organic thiocyanates like Thanite. Some muscular depressants are–phenothiazine, rotenone and ryania.

3. INSECTICIDE MODE OF ACTION GROUPS

A number of new groups of insecticides with different modes of action are being developed and introduced for crop protection; the insecticide mode of action groups presented by AVCARE is furnished here.

Group	Primary Target Site	Chemical Subgroups
1A	Acetylcholine esterase inhibitors	carbamates*
1B		organophosphates*
2A	GABA-gated chloride channel antagonists	cyclodienes
2B		polychlorocycloalthanes
2C		fiproles
3A	Sodium channel modulators	pyrethroids and pyrethrins
4A	Acetylcholine receptor agonist/antagonists	chlornicotinyls
4B		nicotine
4C		cartap, bensultap
5A	Acetylcholine receptor modulators	spinosyns
6A	Chloride channel activators	avermectin, emamectin benzoate
6B		milbemycin
7A	Juvenile hormone mimics	methoprene, hydroprene
7B		fenoxycarb
7C		pyriproxifen
8A	Unknown or non specific action (Fumigants)	methyl bromide

8B		phosphine generating compounds
9A	(selective feeding blockers)	pymetrozine
9B		cryolite
10A	(mite growth inhibitors)	clofentezine, hexythiazox
11A	Microbial disrupters of insect midgut membranes (includes transgenic B.t. crops)	*B.t. tenebrionis*
11B		*B.t. israelensis*
11C		*B.t. kurstaki, B.t. aizawi**
11D		*B.t. sphaericus*
11E		*B.t. tolworthi*
12A	Inhibitors of oxidative phosphorylation, disrupters of ATP formation	organotin miticides
12B		diafenthiuron
13A	Uncoupler of oxidative phosphorylation via disruption of H proton gradient	chlorfenapyr
15A	Chitin biosynthesis inhibitors	acyl ureas
16A	Ecdysone agonists	tebufenozide and related
17A	Homopteran chitin biosynthesis inhibitors	buprofezin
18A	Unknown dipteran specific mode of action	cyromazine
19A	Octopaminergic agonist	amitraz
20A	Site II electron transport inhibitors	hydramethylnon
21A	Site I electron transport inhibitors	rotenone, METI acaricides
22A	Voltage dependent sodium channel blocker	indoxacarb

**all members may not be cross resistant*

[*Source: AVCARE (National Association for Crop Production and Animal Health), October, 1999*]

4. CLASSIFICATION BASED ON CHEMICAL NATURE OF INSECTICIDES

With the advent of more and more newer groups of insecticides, many of them entering the insect body in more than one way, it becomes difficult to classify them based on the mode of entry. This overlapping is avoided if insecticides are classified based on their chemical nature. Two major divisions, viz. inorganic and organic insecticides are recognised. The following is a broad classification of pesticides (includes acaricides, rodenticides and some nematicides also) based on chemical nature.

INSECTICIDES

- Inorganic compounds
  - Arsenicals
  - Flourine compounds
  - Sulphur and lime sulphur
  - Metal Phosphides
  - Other Miscellaneous Compounds
- Organic compounds
  - Hydrocarbon oils, Tar oils, Fixed oils and soaps
  - Animal origin, Nereistoxin
  - Plant origin
  - Synthetic origin compounds

4.1 Inorganic Insecticides

Inorganic insecticides are compounds of antimony, arsenic, barium, boron, copper, fluorine, mercury, selenium, thallium and zinc, which are of mineral origin and elemental phosphorus and sulphur.

Arsenicals Arsenicals are stomach poisons formed of toxic compounds of the apparently non-toxic element arsenic. In an arsenical insecticide the percentage of total arsenic present and the proportion of the water-soluble arsenic have significance. An ideal arsenical insecticide should have very high water-insoluble arsenic content, which should otherwise be readily soluble in the digestive juices of the insect. If the arsenic content is water-soluble, it can enter the foliage and cause "burning" injury to plants. The arsenates are more stable and safer to use on plants than arsenites and hence the latter were used in poison baits and not on plants, as they are phytotoxic. In insects arsenic poisoning causes distintegration of midgut epithelial cells with vacuolised cytoplasm and clumped chromatin of the nuclei. The symptoms of poisoning are regurgitation, torpor and quiescence. Destruction of the insect is primarily due to inhibition of respiratory enzymes.

Arsenicals such as lead arsenate, calcium arsenate, arsenious oxide, sodium arsenite, paris green or copper acetoarsenite, etc. were in use prior to the 1960s. With the synthetic chemicals finding use in crop protection usage of these compounds has been discontinued.

Flourine Compounds Flourine compounds were in use as insecticides since about 1890. They kill insects more rapidly than arsenicals and are less toxic to higher animals and in certain cases safer to use on plants. They are principally stomach poisons and are contact poisons to a limited extent. They are irritating to the appendages of insects. As with arsenicals, the fluorine content and solubility in the digestive juices of the insect are attributed to the insecticidal properties of fluorine compounds. The symptoms of fluoride poisoning are spasms, regurgitation, flaccid paralysis and death. In poisoned insects fluoride combines with magnesium to form magnesium fluorophosphate and thus inhibits phosphate transfer in oxidative metabolism.

Sodium fluoride, sodium fluosilicate, and cryolite or sodium fluoaluminate were in use in the past.

Sulphur and Lime Sulphur

Sulphur: It is primarily a contact poison and in a finely ground dust form (95 % of them passing through a 325 mesh sieve) it is used for insecticidal purposes. The flow of dust is made more free by the addition of about 3 % of the conditioner tricalcium phosphate. Wettable sulphur is prepared by adding a small percentage of wetting agent and also about 0.2 per cent of a synthetic surface active agent. Though sulphur is primarily used as an acaricide it is also used as a diluent for some insecticidal dusts. Sulphur which is commonly used is not toxic other than being irritating to eyes.

Lime sulphur: In 1852 Grison first used it as a fungicide and Dussey in 1886 found it useful in the control of San Jose scale. It is prepared by boiling lime and sulphur together in water. Among the several chemical compounds formed, the polysulphides (calcium pentasulphide and calcium tetrasulphide) are the active materials, which possess insecticidal activity. This has been used for the control of aphids, scales and mites on fruit trees. When liquid lime sulphur is mixed with a stabiliser and evaporated it results in dry lime-sulphur, which in general is less effective than the liquid form.

Metal Phosphides

Aluminium phosphide: It is an insecticidal fumigant. It releases hydrogen phosphide (phosphine, PH_3) in the presence of moisture. It is used for fumigating animal feed, bulk grain, tobacco stakes, etc. to protect them from storage pests and also for space fumigation of warehouses and flour mills. For out-door use it was used for killing rats in burrows. Available in tablets, plates or strips. Its use is permitted under strict supervision by trained and approved personnel/agencies.

Magnesium phosphide: It reacts with atmospheric moisture and releases hydrogen phosphide which is an effective insect-killing gas. It finds use as in the case of Aluminium phosphide. It is available in the form of tablet, strips and plates. The conditions of its usage is the same as in the case of Aluminium phosphide.

Zinc phosphide: It is primarily a rodenticide and is a heavy, dark-grey powder with disagreeable garlicky odour; it was previously used in the control of cockroaches in Europe and mole crickets in Italy. Baits containing 2 % zinc phosphide are recommended for control of rats. In rats the chemical reacts with the hydrochloric acid present in the stomach and releases phosphine gas, which is lethal to the rat.

Other Miscellaneous Compounds: Other compounds which have been found to be stomach poisons of limited use are:

Phosphorus : A paste is prepared by grinding yellow phosphorus in the presence of water and then mixing it with flour a paste is prepared. Sometimes glycerin is added to it. This is used as a bait for cockroaches.

Thallium sulphate: It is a crystalline water-soluble material, which is mixed with a sweet or fatty carrier and used as bait for ants.

Borax or Sodium tetraborate: This finds use in the control of housefly maggots in manure pits. The maggot-infested wounds of animals can be treated and the flies repelled with an emulsion of borax in oil or glyceroboric acid.

Boric acid : It is a stomach poison for cockroaches.

Formaldehyde: It is used in baits for the control of houseflies. Its 40 % solution in water is called formalin.

Metallic mercury: The ointment prepared by incorporating metallic mercury in a heavy oil-like vaseline was used for the control of lice on poultry or on man.

Mercuric chloride and *Mercurous chloride* were used for controlling root infesting maggots and flea beetle larvae. Use of mercuric chloride in book bindings and ant tapes repel ants, cockroaches and termites.

Potassium antimonyl tartarate: It is known as tartar emetic and is a water-soluble salt. It is an ant poison.

Bordeaux mixture: It is a blue coloured suspension prepared by reacting equivalent amounts of copper sulphate with calcium hydroxide. When sprayed it leaves a bluish-white deposit and sometimes repels flea beetles and leafhoppers. However, it is used primarily as a fungicide.

Sodium selenate: It is a water soluble salt. It acts as a systemic poison when applied to soil and brings about control of mites and aphids on ornamental plants in green houses. As it is a cumulative poison, it should never be applied to soil in which food crops will be raised.

4.2 Organic Insecticides

4.2.1 Hydrocarbon Oils

The mineral oils are the petroleum oils derived from sedimentary rocks. Complex solution of hundreds of hydrocarbons are present in the petroleum oils. Kerosene, gasoline lubricating oils, asphalt, tar and many other mixtures are derived from them. In their natural state, oils are highly phytotoxic, but under certain conditions, if applied with an emulsion they may prove to be safe for use on plants. Oils have become increasingly important since 1874 with the discovery of a good formula for a kerosene, soap and water emulsion. They are also used as solvents or carriers for insecticides. In the mineral oil the insecticidal activity is due to certain fractions of the heterogenous mixture of saturated and unsaturated chain and cyclic hydrocarbons in it. The quality of oil is determined by its viscocity, boiling or distillation range, and sulfonation rating, i.e. purity or degree of refinement.

Viscosity is expressed in terms of the time in seconds for 60 ml of oil to flow through a standard orifice at a definite temperature of 100° F. Oils possessing a higher value are not safe for use on plants. It must be borne in mind that the oil from different countries having the same viscocity rating when sprayed on leaves, may react quite differently. Similarly, with the increase in distillation range or boiling phytotoxicity also increases. The lighter oils are more volatile and escape into the air soon whereas the heavier oils exhibit contact with the surface for a longer time due to their less volatile nature and thus prove to be more efficacious against insects.

The non-stable unsaturated compounds in the oil form compounds that are toxic to plants and their amount in the oil is tested by sulfonation test. The unsaturated hydrocarbons in the oil react with strong sulphuric acid when treated and leave the unreacted part, i.e. the sulfonated residue (UR). The UR value is expressed in terms of percentage to interpret the purity of the oil. Highly refined summer oils have a UR rating of 90 to 96 % whereas rating is 50 to 90 % for dormant oils. Following is the classification of insecticidal oils based on the time of usage.

Summer Oils

They are highly refined oils and are less phytotoxic when applied on foliage. The spray concentrations vary from 0.25 to 2.0 % oil. They are used in water emulsion sprays for the control of insect pests like coccids, aleyrodids, and other pests infesting trees, shrubs and ornamentals.

Dormant Oils

They are heavy and less refined oils and are applied on fruit trees and shrubs having no foliage on them during the dormant season. The dormant oil is available in emulsifiable form having 85 to 99 % of actual oil. The spray concentrations vary from two to five per cent of oil. It is sprayed for the control of coccids, aphids, certain mites, etc.

Superior or Supreme Spray Oils

They are again dormant spray oils of high paraffinic and low aromatic content possessing insecticidal action to a satisfactory extent and increased plant safety. They are applied on apple trees from the bud stage up to the time leaves are about 4 cm long for the control of aphids, scales and mites.

Spray Oils

They are diluted with water and applied as an emulsion containing one to four or more per cent oil. When sprayed a continuous film of oil envelops the insects and mites and their eggs, which interferes with their respiration and causes death, by asphyxiation. Spray oils are manufactured from paraffinic-base crudes and naphthenic-base crudes and the preparations of the latter are less effective than the former.

The three types of spray oils in general use are:

(i) *Oil emulsions or concentrated emulsions:* They form stock preparations of fluids or pastes consisting of 80 to 90 % oil emulsified into a small amount of water. The preparation readily mixes with water when added to it in the spray tank.

(ii) *Emulsive or Emulsible oils*: The preparation contains 95 to 99 % oil and an emulsifier. A preliminary agitation is required with a small quantity of water in the spray tank. Certain other formulations of these oils, referred to as *miscible oils*, produce an emulsion instantly when poured into water in a spray tank and the emulsion is stable.

(iii) *Tank-mix oils*: These are prepared just before use and form "quick-breaking" emulsions. In a preparation the oil and spreader are added to the water in the spray tank and emulsified by agitating and pumping.

Oils as solvents and carriers: Diesel fuel is often used as a carrier for toxicant applied by aircraft. In household sprays kerosene (especially deodorised type) is used as a solvent. Oils are relatively cheap and easy to mix with good spreading capacity and low toxicity to animals, and insects have not developed any resistance to them. However, they exhibit relatively low toxicity to most insects and instability in storage. They are phytotoxic and also cause injury to sprayer parts such as rubber hoses.

The lubricating oil-emulsions, the white and summer-oil emulsions, coal tar-oil emulsions, distillate-oil emulsions, kerosene emulsions, carbon bisulphide emulsion and the miscible oils have various trade names.

4.2.2 Tar Oils

Among coal-tar oils creosote oil and green oil or anthracene are useful for insecticidal purposes. Anthracene oils is used for wood preservation.

4.2.3 Fixed Oils and Soaps

Fixed oils are derived from both plants and animals and include oils like castor oil, linseed oil, soybean oil, fish oil etc. They are glycerides and with alkaline bases they saponify or form soaps, setting free glycerin. Fish oil is used in making insecticidal soaps. Soybean oil is also used in insecticides.

Soaps dissolved in water at sufficient quantities act as contact insecticides and have been used for pest control since 1787. A soap is a salt of a fatty acid and an alkali-metal base such as potassium or sodium hydroxide; the former base forms soft soap and the latter, hard soap. The fatty acids are derived from animal and vegetable oils and may include oleic, palmitic or steric acids. Rosin fish-oil soap is available as a commercial insecticide soap and is effective against hairy caterpillars and scale insects. In the preparation of emulsions and as spreaders, wetting agents and stabilisers for pyrethrum and nicotine sprays, soap is used. Soft soaps are used in solution in oils to form the miscible oils.

4.2.4 Animal Origin

Nereistoxin: It is a toxin, chemically known as 4-(N,N-dimethylamino)-l,2-ditholano, isolated from the marine annelids *Lumbrineris* (*Lumbriconereis*) *heteropoda* and *L. brevicirra.* It was found to possess insecticidal activity and in insects caused paralysis due to competitive synaptic blocking action in the central nervous system. Among various related compounds synthesised and tested, the compounds belonging to the group of 1,3-dithiol esters showed insecticidal activity. A product known as cartap, having the chemical name 1,3-bis (carbamoylthio)-2-(N,N-dimethylamino) propane hydrochloride, has been proved to be a practical insecticide against rice stem borer and cabbage diamondback moth.

4.2.5 Botanical Insecticides

Toxicants derived from plants have been and are still used as arrow-tip poisons and fish poisons. Plant products are used in many ways in insect control and among these azadirachtin, nicotine, pyrethrum and rotenone are well known. They are dealt with in a separate chapter.

Volatile Oils from Plants: The volatile or ethereal oils are obtained from special glands of plants and their pungent odour is characteristic of the plant source. The oils are not saponified and are not greasy or viscous. The volatile oils are chiefly used as attractants in baits or as repellents. The attractants include eugenol and geraniol. Citronella and oil of cedar are repellents. Other common examples of volatile oils from plant sources are menthol, camphor, oil of peppermint and wintergreen.

4.3 Synthetic Organic Insecticides

Synthetic organic compounds dominate the field of insecticidal control today. As early as 1892 dinitrocresol was in use as insecticide in Germany and by 1932 several thiocyanates became available commercially. After the Second World War DDT came into prominence as a potent insecticide which revolutionised plant protection. During the World War II certain german scientists developed highly toxic organophosphates and from these insecticides like parathion, TEPP, Schradan, demeton, etc. were obtained. Subsequently in the 1950s carbamates got introduced. In the last four decades vigorous developments have taken place in synthetic chemicals and many new classes of compounds including insect growth regulators, pyrethroids, azadirachtin, etc. have been introduced. Due to intensive research many more new products are being discovered.

The following are some of the important synthetic organics used in plant protection.

4.3.1 Dinitrophenols

The dinitrophenols are derivatives of 4,6-dinitro 2-alkylphenols and their salts or esters.

DINOCAP: It is chemically 2-(l-methyl-n-heptyl)-4,6-dinitrophenyl crotonate or 4,6-dinitro-2-caprylphenyl crotonate. It was first introduced by Rohm & Haas Company in 1946. It is an acaricide and fungicide registered as 48 % EC. Its acute oral LD50 for rat is 980 to 1190 mg/kg.

4.3.2 Organic Thiocyanates:

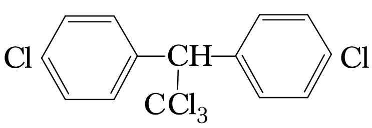
Several insecticides of organic thiocyanates were in use since 1932. They are contact poisons and act on the nervous system of insects. These compounds possess SCN or isothiocyano CNS group and exhibit quick knock down effect.

4.3.3 Organochlorine Compounds

Organochlorine compounds have carbon, hydrogen and chlorine as their basic molecular constituents and some compounds may have oxygen and sulphur also.

DDT

Dichlorodiphenyl trichloroethane ($C_{14}H_9Cl_5$) was first synthesised in 1874 by a German chemist, Othnar Zeidler, but its insecticidal value was not discovered until about 1939 by Paul Muller*. Though DDT is a mixture of substituents, the two isomers *pp'*-DDT and *op'*-DDT are the chief substituents. The principal ingredient of technical DDT, *pp'*-DDT, is 1,1,1–trichloro 2,2,di-(4-chlorophenyl) ethane or 1,1,1-trichloro-2,2-bis(*p*-chlorophenyl) ethane. The structural formula of DDT is:



The product obtained by reacting chloral (or its alcoholate or hydrate) with monochloro-benzene in the presence of concentrated sulphuric acid is technical DDT, which is a white to cream coloured amorphous powder and is composed of up to 14 chemical compounds. The technical product is formed of 65 to 80 % of active *pp'*-DDT, 15 to 21 % of the nearly inactive *op'*-DDT or 1, 1, 1-trichloro-2-(*o*-chlorophenyl) -2-(*p*-chlorophenyl) ethane, up to 4 % of DDD or TDE, up to 0.15 % of l-(*p*-chlorophenyl) 2,2,2- trichloroethanol and

* P. Langer *et al.*, 1944, *Helv. Chim. Acta* **27**: 892.

traces of *O-O'* DDT or 1, 1, 1 -trichloro-2,2-bis-(*o*-chlorophenyl) ethane and bis-*p*-(chlorophenyl) sulfone. The requirements of technical DDT are a setting point of 89° C or above, and presence of 9.5 to 11 % hydrolysable chlorine and less than 1 % volatile and alcohol-insoluble material. Technical DDT is insoluble in water, fairly soluble in most organic solvents and highly soluble in aromatic hydrocarbons such as xylene. In alkaline solution it is dehydrochlorinated to form l.1-dichloro-2, -bis-(*p*-chlorophenyl)ethylene, which has no insecticidal property. However, it is stable under most conditions. It has a very low vapour pressure.

DDT is a contact and stomach insecticide having a longer residual action. It affects the sensory organs and nervous system and causes violent agitation, which is followed by paralysis and death. However, it acts slowly. To mammals it is relatively non-toxic but in oil solution is absorbed by the skin. When animals are fed with foliage treated with DDT, accumulation of the chemical in animal fat and its secretion in the butterfat of lactating animals has been noticed. It is relatively safe for use on large number of crops but exhibits phytotoxicity on sensitive crops like cucurbits. When applied at low concentrations DDT has been found to stimulate plant growth in crops like potato, tomato, brinjal, cabbage, etc. much like plant hormones do. DDT is effective against a wide range of insect pests and several of them have developed resistance to it. As DDT application kills natural enemies of certain groups of insects such as aphids, scales and mealy bugs and also mites, they develop to pest proportions.

In various organisms DDT is metabolised in the following five routes: Oxidised to (i) dicofol in insects, or (ii) dichlorobenzophenone, or (iii) DDA (dichlorodiphenylacetic acid) in vertebrates; (iv) dehydrochlorinated to DDE in animals; and reductive dechlorinated to form DDD or TDE (tetrachloro-diphenylethane) in mammals. In man DDA is the principal metabolite found in the urine. In animals when DDT gets accumulated and stored in fatty tissues it is slowly converted to DDE and finally excreted as DDA. Strains of insect species resistant to DDT possess higher amounts of the enzyme DDT'ase, which converts DDT to inactive DDE. Several DDT analogues also possess insecticidal activities.

Its use in agricultural sector has been withdrawn in India and permitted to be used only for mosquito control under public health programme as 50% WP or 75% WP.

Chlorobenzilate

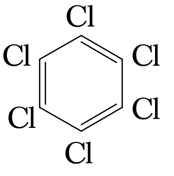
Chlorobenzilate is an acaricide effective against all stages of mites. Gasser in 1952 described its acaricidal properties. It is a yellowish viscous oil. The technical material contains 90 % of the active compound ethyl-*p,p'*-dichlorobenzilate. It is insoluble in water but soluble in benzene, deodorized kerosene and methyl alcohol and gets hydrolysed in alkali and in strong acids to the inactive *p,p'*-dichlorobenzilic acid and ethanol. Its oral and dermal LD_{50} values for rat are 700 to 3200 and 5000 mg/kg, respectively. Its use in the form of strip only has been registered in India.

Dicofol ($C_{14}N_9Cl_5O$)

l,l-bis-(*p*-chlorophenyl), 2,2,2-trichloroethanol or 2,2,2-trichloro-l, l-di-(4-chlorophenyl) ethanol (Dicofol) was reported as an acaricide by Barker, J. S. and F. B. Maugham in 1956[1] and commercially introduced as Kelthane. It is insoluble in water but soluble in organic solvents. It forms the inactive *p,p'*-dicholorobenzophenone and chloroform in the presence of alkali. It is a specific acaricide effective against all stages of mites and is harmless to bees and predators. It has long residual effect. It is used for the control of mites on tea. Its oral and dermal LD_{50} values are 587 to 595 mg/kg for rat and >2000 mg/kg for rabbit, respectively.

HCH

1,2,3,4,5,6-Hexachlorocyclohexane ($C_6H_6Cl_6$) (HCH) was referred earlier as BHC (benzene hexachloride), which is incorrect as HCH could be confused with hexachlorobenzene. Its structural formula is:



This compound was first synthesised in 1825 by Michael Faraday. Its insecticidal properties were described by A. Dupire and by M. Recourt[2] and by R.E. Slade[3]. However, the fact that the insecticidal principle of the technical HCH is the gamma-isomer was made known by F.J.D. Thomas in 1943 in England. HCH is produced by the chlorination of benzene. Among the 13 possible isomers found in varying proportions in HCH, the gamma isomer is insecticidally most active. The gamma isomer comprises about 12.5 % of crude HCH. The crude HCH is greyish or brownish amorphous solid and has a strong musty odour. The crude product consists of 10 to 18 % of the active gamma isomer, four other nearly inactive stereoisomers, viz. 55 to 70 % α-isomer, 5 to 14 % β -isomer, 6-8 % γ-isomer and 3-4 % β isomer, up to 4 % heptachlorocyclohexane and a trace of

1. *J. Econ. Entomol.*, 1956, **49:** 458.
2. *C.R.Hebd. Seances Acad. Agric. Fr.*, 1942, **20:** 470.
3. *Chem. Ind.* (*London*), 1945 p. 134.

octachlorocyclohexane. It is a stable compound but is broken down by alkali principally to 1,2,4-trichlorobenzene and three moles of hydrogen chloride. It acts as a stomach and contact poison and also to some extent as a fumigant. It is more toxic to insects than DDT and finds use in control of mosquitoes. It is also safe to use on a variety of crops but phytotoxic on some especially curcurbits. The oral and dermal LD_{50} values of gamma HCH (lindane) for rat are 200mg/kg and 500 to 1000 mg/kg, respectively. HCH poisoning increases respiration rate and symptoms of poisoning are tremors, ataxia, convulsions and prostration.

It is generally formulated as a 50 % wettable powder or as 5–10 % dust and is used for the control of a wide variety of pests of crops. In some treated plants, especially vegetable crops, HCH taints or produces off-flavour. When applied to soil for control of soil pests of tuber crops or on foliage of edible crops it sometimes causes severe tainting as in potato, lettuce, etc. and makes them unpalatable. When applied as a dust or spray it is very irritating to mucous membranes and eyes. Use of HCH in India has been withdrawn.

Lindane

The product containing gamma isomer of HCH of not less than 99 % purity is commonly referred to as lindane and the name was proposed in 1949 after Van der Linden, a German chemist who isolated this isomer in 1912. It is white to colourless, crystalline, odourless, unstable in the presence of alkali and does not accumulate in the fat of animals to any marked extent. It is a contact and stomach poison and has some fumigant properties. Lindane is safer than HCH on plants but more toxic to insects. It is formulated as 20 % emulsifiable concentrate, which is useful for the control of a large number of insect pests, especially the sugarcane shoot borer. Lindane 0.65 % dust is used for the control of pests of vegetable crops and stored products. Lindane 10 % granule has been reported to be effective in controlling the rice yellow borer.

4.3.4 Cyclodiene Insecticides

These are highly chlorinated cyclic hydrocarbons with "endomethylene-bridged" structures, prepared by the Diels-Alder diene reaction. The toxicity of the compounds is attributed to their high lipoid solubility. Though they are known to act on the ganglia the precise bio-chemical lesion responsible for toxic action is not understood. Symptoms of poisoning are hyperactivity, convulsions and prostration.

Chlordane

Chlordane ($C_{10}H_6Cl_8$) or Octachlor is 1,2,4,5,6,7,10,10 - Octachloro - 4,7,8,9-tetrahydro-4,7 methyleneindane. In 1945 C.W. Kearns* and his associates described its insecticidal properties. The technical material is a brown viscous liquid and has a odour resembling cedar. It has a light fumigant action but also possesses some residual activity. It is a stomach and contact poison. It is toxic to bees. Its oral and dermal LD_{50} values for rat are 283 and 1600 mg/kg respectively. Its use in India has been withdrawn.

Heptachlor

Heptachlor is 1,4,5,6,7,10,10 heptachloro-4,7,8,9-tetrahydro-4,7-methyleneindane. The technical product containing about 67 % heptachlor is a soft waxy solid. It is a nerve poison. Its oral and dermal LD_{50} values for rat are 40 and 200-250 mg/kg respectively. Heptachlor residues are slowly converted to heptachlor epoxide in and on plants and in animal tissues and this has the same mammalian toxicity and insecticidal activity. It was recommended for the control of grasshopper, soil insects like white grubs, wire-worms, termites, etc. Its use in India has been withdrawn.

Aldrin

Aldrin is 1,2,3,4,10 10-hexachloro-l,4,4a,5,8,8a- hexahydro-*exo*-l, 4-*endo*-5,8-dimethanonaphthalene. The name Aldrin was given to the chemical to honour the German chemists Kurt Alder and Otto Diels who received the Nobel Prize in Chemistry in 1950 for their work on diene synthesis used in formulation of cyclodiene insecticides. In the living tissues of plants, mammals and insects aldrin gets rapidly converted to dieldrin. Its oral and dermal LD_{50} values for rat are 40 to 50 and 200 mg/kg respectively.

It has considerable residual effectiveness and was used as a soil insecticide for the control of termites, white grubs, etc. It was used in the control of locusts and grasshoppers in India. Its use in India has been withdrawn.

Dieldrin

Dieldrin is 1,2,3,4,10,10-hexa-chloro-6-7-epoxy-l,4,4a,5,6,7,8,8a-octahydro-*exo* l,4-*endo*-5,8-dimethanonaphthalene or the epoxide of aldrin. Dieldrin was named after the German chemist Otta Diels. The acute oral and dermal LD_{50} values for rat being 40 and 100 mg/kg respectively. It was useful in the control of pests infesting crops, in household

* *J. Econ. Entomol.*, 1945, **38:** 661.

sprays for the control of cockroaches, flies and mosquitoes, and in the control of termites, grubs and larvae feeding on roots of plants. The formulation 18% solution is registered in India.

Endrin

It is l,2,3,4,10,10-hexachloro-6-7-epoxy-l,4,4a,5,6,7,8,8a-octohydro-*exo*-l,4-*exo*-5,8-dimethano-naphthalene or the *exo exo* isomer of dieldrin. Its use in India has been withdrawn.

Endosulfan

Endosulfan, is 6,7,8,9,10,10-hexachloro- l,5,5a,6,9,9a- hexahydro -6,9 methano-2,4,3-benzo(e)-dioxathiepin-3-oxide. It is both a chlorinated hydrocarbon and an organic sulphite. Its empirical formula is $C_9H_6Cl_6O_2S$. In 1956 W. Finkenbrink* described its insecticidal properties. The technical material is a brown crystalline solid, insoluble in water but soluble in xylene. It consists of two stereoisomers, viz. α and β stereoisomers, and inactive 1,4,5,6,7,7 hexachloro-2, 3-bis- (hydroxy-methyl)-bicyclo-(2.2. l)-heptene-5. It has a slight fumigant action besides being a stomach and contact poison. It has been found useful in the control of aphids, caterpillars, plant bugs and borers. Its use does not encourage secondary infestation of mites. It is not harmful to bees and natural enemies of pests. It is formulated as 35 % emulsion concentrate. Its acute oral and dermal LD_{50} values for rat are 110 and 74 to 130 mg/kg respectively.

4.3.5 Organophosphorus Insecticides

These insecticides are characterised by the molecule having one or more rarely two atoms of phosphorus, and are usually derivatives of phosphates (PO_4). In Germany during World War II Schrader discovered the insecticidal potency of this chemical group and since then a large number of compounds have been synthesised. They mainly act as contact and stomach poisons; and some are systemic, some slowly give out vapours which have fumigant action. The phosphorus esters owe their biological activity to inhibition of enzyme cholinesterase and this is determined by the magnitude of the electrophilic character of the P atom, the strength of the P-X bond and the steric nature of the substituents. It has been shown that the phosphate esters (P-O) are more active as the P is much more electrophilic than in the phosphorothionate esters (P-S), the latter, being stable, is activated by oxidation to the corresponding P-O compound in the animal body. The P-X bond of the toxicant is broken during inhibition process due to its bimolecular reaction with enzyme cholinesterase. In the highly toxic compounds strong electron withdrawing

* *Nachrichtenbl.Dtsch.Pflanzenschutzdienstes* (*Brawnschweig*) 1956, 8 : 183.

substituents, such as p-NO_2 and CH_3S, may be found. Similarly the alkyl and alkoxy substituents of phosphates and phosphonates also influence the electrophilic nature of P atom. Decrease in toxicity and increase in stability has been noticed with increasing chain length and with chain branching of the compounds. Further, incorporation of –Cl or –CH_3 in the meta position of the aryl ring of parathion-type compounds reduces the mammalian toxicity appreciably without affecting its insecticidal activity.

In higher animals and insects cholinesterase is an essential constituent of the nervous system. Therefore, the capacity of the central P atom of the organophosphorus toxicant to phosphorylate the esteratic site of the enzyme cholinesterase contributes to the biological activity of the compound. The phosphorylated enzyme is irreversibly inhibited. This disrupts the normal function of rapid removal and destruction of acetylcholine from the nerve synapse. As a result acetylcholine responsible for transmission of nerve impulses across the synapse accumulates and causes derangement of the nervous mechanism and death.

Symptoms of poisoning due to organophosphorus compounds are hyperactivity, tremors, convulsions, paralysis and death in insects and muscarinic effects such as nausea, salivation, lachrymation and myosis, nicotinic effects such as muscular fasciculations and central effects such as giddiness, tremulousness, coma and convulsions in higher animals.

The organophosphorus pesticides are classified, based on the way in which the phosphorus atom is found in the combination, into phosphates, phosphonates, phosphor othionates, phosphorothiolates, phosphorothiolothionates (phosphorodithioates), phos phonothiolothionates (phosphonodithioates), phosphonothionate, phosphoramidate, phasphoramidothioate, etc.

The following are some important compounds among different groups of organo-phosphorus chemicals used in crop protection.

Acephate

Acephate, $C_4H_{10}NO_3PS$, is *O, S*-dimethyl acetyl-phospharamidothioate. It is a white solid; melting point 82-89°C; specific gravity. 1.35; volatility low, relatively stable; solubility is approximately 65 % in water but relatively low being less than 5 to 10 % in organic solvents. It is an insecticide of moderate persistence with residual systemic activity. It is effective against caterpillars, lace bugs, leaf miners, leaf rollers, leafhoppers, mealy bugs, thrips, etc. It is formulated as 75 % soluble powder. Its acute oral LD_{50} to rat is 866-945 mg/kg, dermal for rabbit >2000 mg/kg.

Cadusafos

It is a nematicide and soil insectcide. Chemically it is O-ethyl S,S-di-sec-butyl phosphorodithioate or O-ethyl S,S-bis(1-methylpropyl) phosphorodithioate. Cadusafos 10%G has been found effective against banana nematode when applied at 20-30 g/plant. The acute oral LD_{50} for rat is 679 mg/kg (male), 391 mg/kg (female); dermal rabbit 155 mg/kg (male), 143 mg/kg (female) in respect of 10% G.

Chlorfenvinphos

Chlorfenvinphos, $C_{12}H_{14}O_4C_{13}P$, is combined isomers of 2-chloro-1-(2,4-dichlorophenyl) vinyl diethyl phosphate. Technical material contains not less than 92 % (weight) active *trans* and *cis* isomers of the toxicant. It is an amber liquid with a mild chemical odour and is not inflammable. It is slightly soluble in water and miscible with acetone, xylene, alcohol, kerosene, corn oil and propylene glycol. It decomposes very slowly in the presence of water. Its acute oral and dermal LD_{50} values for rat are 10 to 155 and 108 mg/kg respectively. It is a contact insecticide and in some cases may be translocated in plants. It is active against pests belonging to orders Diptera, Lepidoptera and Coleoptera. It is particularly useful for the control of rootfly larvae, Colorado potato beetles, cereal leaf beetles and corn rootworms. It is effective against pests resistant to chlorinated hydrocarbons. It does not leave any harmful residues in crops and soil at normal recommended dosages. Formulation registered in India is 10% Gr.

Chlorpyriphos or Chlorpyrifos

Chlorpyriphos is O, O-diethyl O-(3,5.6-trichloro-l-pyridyl) phosphorothioate. Its empirical formula is $C_9H_{11}Cl_{13}NO_3PS$. It is a white crystalline substance with mild mercaptan odour; m.pt. 41.5 - 43.5°C. It has extremely low solubility in water but readily soluble in most organic solvents. It is relatively stable to hydrolysis and oxidation. It is slowly hydrolysed to 3,5,6- trichloro-2-pyridinol. It may not probably be compatible with highly alkaline materials especially Bordeaux mixture and liquid lime-sulphur. It is a contact and stomach poison with vapour action also. Its acute oral LD_{50} for female rat is 135 mg/kg, male rat 163 mg/kg: dermal for rabbit 1000 to 2000 mg/kg. It is effective against many pests of rice and other crops, mosquitoes and household pests, soil inhabiting insects particularly termites and certain mites. It is applied at a dosage rate ranging from 0.05 to 0.5 kg a.i./ha depending on the pest species. Formulations registered are 20%EC and 10% Gr and 50% EC for termite control.

Coumaphos

Coumaphos, is 3-chloro-4-methyl-7-coumarinyl diethyl-phosphorothionate or O,O-diethyl-O- (3-chloro-4-methyl-2-oxo-2H-l-benzopyran-7-yl) phosphorothionate. It is a tan crystalline solid, insoluble in water and soluble in organic solvents. It is a systemic insecticide used in the control of animal pests. Its acute oral and dermal LD_{50} for rat are 13 to 180 and 860 mg/kg respectively. Its trade names have been Asuntol, Co-Ral, Muscatox, etc.

Diazinon

Diazinon, $C_{12}H_{21}N_2O_3PS$, is a phosphoric acid ester. It is diethyl 2-isopropyl-6-methyl-4-pyri- midinyl phosphorothionate (or) Thiophosphoric acid-(2-isopropyl-4-ethyl-pyrimidyl-(6)-diethylester. It is a colourless liquid with a slight characteristic odour. It is soluble to 0.004 % in water and mixes with ether, alcohol, benzol and similar hydrocarbons and with deodorised kerosene, cyclohexane and petroleum ether. It is hydrolysed in alkalis and acids. The technical product is 90% pure, clear yellowish-ochreish slightly viscous liquid with a characteristic odour. It is a contact and stomach poison and has a fumigant effect and penetrative quality. Its acute oral and dermal LD_{50} for rat are 150 to 220 and 500 to 2,000 mg/kg respectively. Diazinon is chiefly useful in the control of resistant houseflies, bedbugs, ectoparasites on animals, insect pests of crops and certain mites. It has also a nematicidal effect. Diazinon gives excellent control of ectoparasites on domestic animals and it is chiefly used for dipping and spraying cattle and sheep. It controls all the major ectoparasites and protects the sheep from primary blowflies. Diazinon is not eliminated with milk.

In agriculture diazinon is useful in the control of a wide variety of pests of crops. It is effective against lepidopterous larvae, bugs, thrips, beetles, flies and certain mites. It has proved to be an outstanding chemical for the control of most sucking insects, borers and leaf caterpillars and gall midge on rice when applied in granular form at 1.5 to 2 kg active ingredient/ha. Diazinon is also effective against soil pests. It is effective against cabbage rootfly, onion maggot, turnip maggot, seed corn maggot, wheat bulbfly, carrot rustfly, wireworms, lepidopterous larvae, field cricket, lettuce root aphid, and certain myriapods infesting potatoes in France and Belgium.

Formulations are: 40% WP, 20,25 or 60% EC, 2–5% dust and 5 or 10% granule.

Dichlorvos (DDVP)

Dichlorvos ($C_4H_7O_4Cl_2P$) is 2,2-dichlorovinyl dimethyl phosphate or O, O-dimethyl -2, 2-dichlorovinylphosphate. It is a pleasant smelling, colourless liquid. It is soluble in water and most organic solvents. It gets hydrolysed slowly in neutral and acid media and rapidly in alkaline medium. Its acute oral and dermal LD_{50} values for rat are 25 to 30 and 75 to 900 mg/kg. It is moderately toxic to fish and highly toxic to bees. It acts as a contact, and stomach poison and fumigant and has good penetration properties. It brings about rapid knockdown of the insect. As the toxicant volatilises soon after application, it can be used on all crops until shortly before harvest and it also does not impart any taint. It has no ovicidal action. It is used in baits and aerosol formulations for the control of insects of home and public health such as flies and mosquitoes in open places and for the control of insects of stores and food processing plants such as flies and moths in stores, mills, bakeries, dairies, etc. It is also useful for the control of insect pests of mushrooms.

It is effective against locusts when applied from aircraft at 80 to 120 g active ingredient/ha. Dichlorvos is also effective against pests of crops such as lepidopterous larvae, leaf miners, sucking insects and mites. It is available as 76% SC in India. It is useful in the control of cockroaches.

Dimethoate

Dimethoate (C_5HOPSN) is dimethyl S (N-methyl carbamoylmethyl) phosphorothiolothionate or N-monomethyl-amide of O,O-dimethyl-dithiophosphoryl-acetic acid or O, O-dimethyl-S (mercapto-N-methyl-acetamides) dithiophosphate or 0,0-dimethyl-S (N-methyl-carbarnoyl-methyl) phosphorodithioate.

It is a white crystalline solid with slightly mercaptanic odour. Technical material contains 94 to 96 per cent dimethoate, white crystalline solid with unpleasant odour. It is soluble in a number of organic solvents such as chloroform, alcohol, ethyl ether, acetone, benzens, toluene, cyclohexanone, acetophenone, etc. It is rather unstable in alkaline media. Its acute oral and dermal LD_{50} to rat respectively are 200 to 300 and 700 to 1150 mg/kg. It is a systemic and contact poison effective against sucking insect pests and mites of a wide variety of crops and fruitflies. It is phytotoxic on certain varieties of sorghum, some varieties of hops (Golding) and olives (Coratina, Vernina, Marsella), figs, chrysanthemums, begonia and jacobinias. Neither dimethoate nor its biologically active conversion products can be detected three to four weeks after treatment. Dimethoate 30 % EC registered in India.

Disulfoton or Thiodemeton

Disulfoton ($C_8H_{19}O_2PS_3$) is diethyl S-2-(ethylthio) ethyl phosphorothilothionate or O,O-diethyl-S-2-(ethylthio) ethyl phosphorodithioate. It is a colourless oily liquid with characteristic odour, soluble in most organic solvents such as acetone, alcohol, ether, etc. It is a systemic insecticide and acaricide possessing residual action for 6 to 12 weeks. Its acute oral and dermal LD_{50} to rat are 4 and 50 mg/kg respectively. It is applied as a granule or used in seed dressing. Sufficient moisture should be present in the soil for it to act effectively. It is recommended at dosages varying from 1 to 2 kg active ingredient per hectare for the control of sucking insects and mites infesting rice, cereals, potato, cotton, groundnut, coffee, beans, peas, cabbage, tomatoes and ornamental plants. It is also effective against sorghum shootfly. Formulation: 5 % granule.

Ethion

Ethion ($C_9H_{22}O_4P_2S_4$), is tetraethyl SS'-methylene bis- (phosphorothiolothionate) or 0, 0, 0', 0'-tetraethyl -S,S'-methylene bis phosphorodithioate. It is slightly soluble in water and miscible in xylene, methylated naphthalene and kerosene. Its acute oral LD_{50} for rat is 96 mg/kg and dermal LD_{50} for rabbit is 915 mg/kg. It is useful for the control of many aphids, scales, leaf miners, leaf hoppers, pear psylla, sorghum midge, codling moth, seed corn maggot, onion maggot, Lygus bugs, thrips and mites (including eriophyid mites). It is phytotoxic on certain apple varieties. Formulation registered in India is 50% EC.

Fenitrothion

Fenitrothion ($C_9H_{12}P_5NPS$) is dimethyl 3-methyl-4-nitrophenyl phosphorothionate or 0,0-dimethyl-0-(3-methyl-4-nitrophenyl) phosohorothioate. Technical material is 95 % pure, yellowish brown oily liquid with a faint smell. It is insoluble in water, soluble in alcohol, ether and low boiling aromatics. It is unstable in alkaline medium. Its acute oral and dermal LD_{50} for rat are 250 to 673 and 1500 to 3000 mg/kg respectively. It is toxic to bees. It is a contact and stomach poison and has a good depth action. Phytotoxicity may be caused on *Brassica* crops and certain susceptible apple varieties and on cotton at high dosages. It is recommended against a wide range of pests of crops and certain mites, and especially for the control of pests of rice. It is also used for the control of mosquito larvae, bed bugs and poultry lice, fleas, mites, ticks and ectoparasites of livestock and pet animals. Formulations are: 50 or 82.5% EC, 5% dust, 40% WDP and 5% Gr. Suitable formulations for application at ultra low volume rates are also available.

Fensulfothion

Fensolfothion ($C_{11}H_{17}O_4PS_2$) is diethyl 4-(methyl sulphinyl) phenyl phosphorothionate or 0,0-diethyl-O- (4-methylsulfinyl-phenyl) -monothiophosphate. It is a yellowish brown liquid, soluble in most organic solvents. Its acute oral and dermal LD_{50} for rat are 2 to 11 and 3 to 30 mg/kg respectively. It is a systemic and contact poison with very long residual effect. It is a nematicide and insecticide. It is applied to the soil in granular formulation for the control of free-living, cyst and root-knot nematodes, and soil-inhabiting larvae of Lepidoptera, Diptera and Coleoptera. Its systemic action effects control of sucking and biting insects on different crops. Formulations: 5 or 10 % granule.

Fenthion

Fenthion ($C_{10}H_{15}O_3PS_2$) is dimethyl 3-methyl-4-methylthiophenyl phosphorothionate or 0,0-dimethyl-0-4-methylmercapto-3-methyl-phenyl)-thiophosphate. It is a colourless oily liquid, sp. gr. 1.25; practically insoluble in water (54 to 56 mg/litre), limited solubility in petroleum ether and readily soluble in most organic solvents. Its acute oral and dermal LD_{50} for rat are 200 and 1300 mg/kg respectively. It is a contact and stomach poison possessing depth action and long residual effect. It is a broad spectrum insecticide particularly effective against fruit-flies, leafhoppers, cereal bugs, rice stem borers and mango nut weevil. It is also used in the control of mosquito larvae and bed bugs. It is harmful to bees. It may be phytotoxic on sensitive cotton and apple varieties such as "golden" or "delicious."

Formulations are: 50 or 82.5 % emulsifiable concentrate, ULV formulation, 5 per cent dust and 20 % EC for use in the control of pests of public health.

Formothion

Formothion ($C_6H_{12}O_4PS_2N$) is S-(N-formyl-N-methyl carbamoylmethyl) dimethyl phosphoro-thiolothionate or O,O-dimethyl S-(N-methyl-N-formyl-carbamoyl-methyl-dithiophosphate. It is a yellowish viscous oil or crystalline solid with a faint characteristic smell. Its acute oral and dermal LD_{50} to rat are 400 and 400 to 1680 mg/kg respectively. It is a systemic insecticide and acaricide with contact action, effective against various sucking insects and mites on crops. Formulated as 25 % emulsifiable concentrate.

Malathion

Malathion ($C_{10}H_{19}O_6PS_2$) is S-l,2-di (ethoxycarbonyl) ethyl dimethyl phosphoro-thiolothionate or 0,0-dimethyl S- (1,2-dicarbethoxyethyl) phosphorodithioate. It is a brownish liquid. The technical material is 95 to 98 per cent pure with an unpleasant odour. Its specific gravity at 25° C is 1.23, soluble in water to 0.0145 %, slightly soluble in mineral oils and soluble in most organic solvents. It is unstable in alkaline medium. It is one of the safest chemicals available, its acute oral and dermal LD_{50} to rat being 1400 to 1900 and 4000 mg/kg respectively. At the recommended dosages it can be applied to most edible crops within one to three days of harvest without danger of excess harmful residues. It is a contact and stomach poison used for the control of a wide variety of pests of crops such as aphids, hoppers, psyllids, plant bugs, aleyrodids, flea beetles, grey weevils, caterpillars, hispa, mealy bugs and scales, thrips, etc. and red mites on arecanut. In public health it is used in out-door and residual sprays for the control of mosquitoes, in breeding sites for the control of flies and in households for the control of bed bugs. In animals it is quite useful for the control of lice, fleas, ticks and mites infesting cattle, chicken, goat, sheep and dogs. Formulated as 50 % EC, 25 % WP, 5 % dust, 10 % granule and 0.25% spray. Malathion low volume concentrate formulation containing 96 % active ingredient is applied undiluted with water for the control of pests of paddy, cotton, wheat, redgram, sugarcane, vegetables, millets, etc. and for the control of grasshoppers and locusts. Granular malathion is recommended at 1.5 kg active ingredient per hectare for the control of borers of sorghum and *Pennisetum typhiodeum.*

Methyl Parathion

Methyl parathion ($C_8H_{10}NO_5PS$) is 0,0-dimethyl-O-nitrophenyl phosphorothionate. It is less toxic to mammals but highly toxic to insects than parathion. LD_{50} for rat: oral 14-24 mg/kg, dermal 67 mg/kg. It is used against a wide range of pests of crops. Formulations registered are 2% dust and 50% EC.

Monocrotophos

Monocrotophos ($C_7H_{14}O_5NP$) is dimethyl *cis*-1-methyl-2-methylcarbamoylvinyl phosphate or *cis*-(2-methylcarbamoyl-1-methylvinyl)-dimethylphosphate or dimethyl phosphate of 3-hydroxy-N-methyl-*cis*-crotonamide. It is made up of colourless crystals with mild ester smell, miscible with water, acetone and alcohol; sparingly soluble in xylene and very sparingly soluble in kerosene and diesel fuel. It is rapidly hydrolysed in alkaline solutions than in acids. It is a hazard to wild life if the food is contaminated with residues above 0.5 ppm. It is toxic to bees and at normal application rates it appears to be safe for fish and oysters. It is a systemic insecticide as it is absorbed by the plant roots and is translocated in the xylem into stems and leaves. It acts as a stomach and contact poison. Three major pathways are recognised in the metabolism of monocrotophos in plants and animals. These are hydrolysis at the vinyl-phosphate bond; at the methyl-phosphats bond and an oxidative process, the latter giving rise to N-hydroxymethyl amide and the unsubstituted amide of monocrotophos, which are comparable to those of the parent compound in their toxicities. In certain varieties of cherry and some varieties of sorghum it causes scorching of the edges of leaves. Its acute oral LD_{50} for rat is approximately 20 mg/kg. Dermally, the LD_{50} for rabbits is 342 (154–760) mg/kg. It is not an eye-irritant.

It is effective against thrips, aphids, aleyredids, leaf miners, cotton bollworms, leaf webbers, and a number of other in sect pests and mites of crops. Formulation: 36%SL.

Oxydemeton-Methyl

Oxydemeton ($C_6H_{15}O_4PS_2$) is S -(2-ethyl-sulphinyl) ethyl dimethyl phosphorothiolate or 0, 0-dimethyl-S-2-(ethyl sulphinyl) ethylthio-phosphate. It is a yellowish liquid, odourless, miscible with water, soluble in most organic solvents and practically insoluble in petroleum ether. It is unstable in an alkaline medium. It is a systemic insecticide effective against sucking insects and mites. It is very largely harmless to parasites and predators but harmful to bees. Its acute oral and dermal LD_{50} for rat are 57 and 100 mg/kg respectively. Formulated as 25 % EC.

Phenamiphos

Phenamiphos, $C_{13}H_{22}NO_3PS$, is O-ethyl-O-(3-methyl-4-methylthio-phenyl)-isopropyla mido-phosphate; or lsopropyl-phosphoroamidic acid-O-ethyl-(3-methyl-4-methyl-thiophenyl)-ester. It is a white crystalline material; solubility 700 ppm in water at 20°C; slightly soluble in organic solvent besides petroleum ether. It is a systemic nematicide effective against root-knot nematodes, cyst-forming nematodes and free-living nematodes. It also controls sucking insect pests and spider mites. When applied to foliage it is translocated basipetally to the roots, kill nematodes living in the roots, and protects the plants against further nematode infestation. Its formulated as 5 and 10% granule and 40% EC. Its acute oral LD_{50} for rat is 15.3 to 19.4 mg/kg, dermal 500 mg/kg.

Phenthoate

Phenthoate is S-*alpha*-ethoxycarbonylbenzyl dimethyl phosphorothiolothionate or O,O-dimethyl S-*alpha*-ethoxycarbonylbenzyl phosphorodithioate or ethyl ester of O,O-dimethyl-dithiophosphoryl *alpha*-phenyl acetic acid or ethyl mercaptophenylacetate O,O-dimethyl phosphorodithioate. The pure compound is of colourless crystals with light aromatic odour. The technical material containing 90 to 92 % phenthoate is an oily liquid, reddish yellow, aromatic. Its acute oral and dermal LD_{50} for rat are 200 to 300 and 700 to 1400 mg/kg respectively. It is a wide spectrum insecticide and acaricide, effective against lepidopterous borers and leaf feeders, sucking insects, sawfly larvae, etc. and tetranychid and eriophyid mites. It is effective for the control of mosquito larvae at concentrations lower than those found to be toxic to fish and also for adults. It can also be used for the control of external mites and insects on domestic animals. It is phytotoxic on some vine, peach and apple varieties.

The metabolism of phenthoate in plant tissues comprises of oxidation and hydrolysis. Oxidation results in oxygen homolo gue of phenthoate, which is insecticidally active. Hydrolysis results in inactive products among which phosphoric, dimethylphosphoric and monomethyl phosphoric acids have been identified. At recommended dosages it does not leave any harmful residues in edible parts of plants. Formulated as liquid containing 50 % active ingredient; oil formulation containing 5 % active ingredient and 80 % mineral oil (UR 89 per cent); wettable powder containing 40 % a.i., powder containing 3 % a.i. and granule containing 2 % a.i.

Phorate

Phorate ($C_7H_{17}O_2PS_8$) is diethyl S-(ethyl-thiomethyl) phosphorothiolothionate or O, O-diethyl S-(ethylthio) methyl phosphorodithionate. The technical grade containing not less than 90 % phorate is a clear mobile liquid. It has low solubility in water, approximately 50 ppm, but miscible in xylene, vegetable oils, carbon tetrachloride, alcohols, ethers and esters. It gets hydrolysed in the presence of moisture and alkaline conditions. It is a systemic insecticide and is absorbed by roots and subsequently translocated to aerial parts of the plant. When absorbed by plants phorate is initially and rapidly oxidised to its insecticidally active sulfoxide and sulfone: which in turn are converted to sulfoxide and sulfone of the phorate oxygen analogue. These active compounds on hydrolysis are broken down to various inactive thio- and phosphoric acids and esters. It has also contact and fumigant action. In addition to being an insecticide it has also shown some nematicidal and acaricidal action. Its LD_{50} oral and dermal for rat are 16-37 and 2.5-6.2 mg/kg respectively. It has been found useful in the control of sorghum shootfly, aphids on groundnut and potato, sucking pests of cotton, tobacco and vegetables, sucking insects and gallmidge on rice, etc. Granules containing 10 % phorate is applied, depending on the crop, before planting or sowing, at planting or sowing or transplanting or after transplanting.

Phosalone

Phosalone, $C_{12}H_{15}ClNO_4PS_2$, is O,O-diethyl-S-(6-chloro-l.3 benzoxazol-2 (3H)-onyl-methyl) phosphorodithioate; (or) O,O-diethyl S-(6-chlorobenzoxazolinyl-3-methyl) dithiophosphate; (or) 3-O, O-diethyl dithiophosphorylmethyl-6-chlorobenzoxazolone. It is a white crystalline substance with alliaceous or garlicky odour; practically insoluble in water, but highly soluble in many organic solvents. It is relatively stable in acid medium but rapidly hydrolysed in alkaline medium to the principal products 6-chlorobenzoxazolone, diethylthio-phosphoric acid, and formaldehyde. It is oxidized to the relatively unstable 0,0-diethyl S-(6-chlorobenzoxazolmyl-3-methyl) thiophosphate, which is assumed to be the first metabolite of phosalone in plants and it quickly breaks down.

Phosalone is also rapidly degraded in animal tissues. Its acute oral LD_{50} for rat is 135 mg/kg, dermal 1500mg/kg. It is recommended for the control of insect pests of various crops and mites. Treatment of seeds with phosalone also affords protection to seedlings from damage by insects and mites. It is moderately toxic to bees. It is formulated as 35 % EC, 30 % WP, 2.5 % and 4 % dust.

Phosphamidon

Phosphamidon ($C_{10}H_{19}O_5NClP$) is 0-(2- chloro-2-diethyl-carbamoyl)-1-methylvinyl) - 0, 0-dimethyl phosphate (or) 0,0-dimethyl-0-(l-methyl-2-chloro-2-diethyl-carbamoyl-vinyl) phosphate (or) 0,0-dimethyl-0-(diethylamido-l-chloro-crotonyl-2) phosphate or O-(1-chloro-l-diethyl-carbamoyl-1 -propen-2-yl)-0,0-dimethyl phosphate (or) 2-(0,0-dimethyl phosphoryloxy)-l-chlorocrotonic acid diethylamide. It is colourless to pale yellow with faint, pleasant odour. Technical grade is dark brown and commercial product is bright violet due to addition of a dye. It is miscible in water and all organic solvents except saturated hydrocarbons in which it is soluble only to a limited extent. Technical grade contains 92 % pure. The insecticidal activity of phosphamidon is mostly due to its β-isomer and the isomers α and β are found in the ratio of 3:7. Technical grade phosphamidon is very stable. It is a systemic insecticide and acts as a stomach poison, and has a relatively low contact action. Metabolism of phosphamidon gives to desethylphosphamidon, which is roughly as toxic as the parent compound, and is rapidly broken down by the plant. Phosphamidon is of relatively very low toxicity to fishes but toxic to bees. It is phytotoxic on some cherry varieties. It corrodes iron, tin plate and aluminium. Its acute oral and dermal LD_{50} values for rat are 15 and 125 mg/kg respectively. It is effective against many sucking, chewing and mining insects and certain mites. It is widely used for the control of yellow borer and other sucking pests of rice. Formulation: 50% SL.

Pirimiphos-methyl

It is O-(2-diethylamino-6-methylpyrimidin-4yl) O,O-dimethyl phosphorothioate. Its acute oral LD_{50} for rat is – oral >2000 mg/kg, dermal 4592 mg/kg. It is a fast acting broad spectrum insecticide effective against wide range pests of stored grains. It finds use in household pest control as 1% spray or 2% acrosol.

Profenofos

It is an insecticide and acaricide. Chemically it is O-4-bromo-2-chlorophenyl O-ethyl S-propyl phosphorthioate. Technical grade solution is an amber coloured liquid with garlic-like odour. It is readily miscible with organic solvents. Its acute oral LD_{50} for rat is

358 mg/kg; dermal for rabbit 277 mg/kg. It is registered as 50% EC and controls a wide range of pests at 500 g a.i./ha.

Propetamphos

It is (E)-O-2-isopropoxycarbonyl-1-methylvinyl O-methyl ethylphosphoramidothioate. Its acute LD_{50} for rat - oral 119 mg/kg, dermal 2825 mg/kg. It is a contact insecticide with stomach action. It is used for control of public health pests such as cockroaches, flies, fleas, mosquitoes, etc. as 1% spray.

Quinalphos

Quinalphos ($C_{12}H_{15}N_2O_3PS$) is O, O-diethyl-O-(quinoxalinyl (2)) -thionophosphate. It is an odourless white crystalline solid. Its solubility in water is 22 ppm at 24° C, but readily soluble in methyl and ethyl alcohol, ethyl ether, acetone, ketones, and aromatic hydrocarbons such as benzene, toluene, xylene, etc. It is hydrolysed in alkaline medium. Its acute oral LD_{50} for male rat is 137 mg/kg and dermal 1400 mg/kg. It is an insecticide effective against a wide spectrum of insect pests of crops. It is an effective acaricide too. It is formulated as 25% EC, 1.5% dust and 5% Gr.

Temephos

It is O,O'-thiodi-4,1-phenylene-O,O,O'O'-tetramethyl phosphorothioate. Its acute oral LD_{50} for rat is 4204 mg/kg (male), 10000 mg/kg (female), dermal (rabbit) 2000 mg/kg (male), 2378 mg/kg (female). It finds use as a mosquito and midge larvicide.

Thiometon

Thiometon ($C_6H_{15}O_2PS_3$) is S-2-(ethylthio) ethyl dimethyl phosphorothiolothionate or O, O-dimethyl-S-ethyl mercaptoethyl-dithiophosphate. It is a systemic insecticide effective against aphids and other sucking insects, sawflies and mites. Its acute oral and dermal LD_{50} to rat are 100 and 200 mg/kg respectively. It is formulated as 25% EC.

Trichlorphon

Trichlorphon or Trichlorfon ($C_4H_8Cl_8O_4P$) is dimethyl 2,2,2-trichloro-l-hydroxyethyl phosphonate or 0,0-dimethyl-(2,2,2-trichloro-l-hydroxyethyl phosphonate). It is a white crystalline powder. It is soluble in water but readily soluble in low alcohols, ketones, aromatic hydrocarbons, chlorinated hydrocarbons (methylene chloride, chloroform) and dimethyl sulphoxide. It is insoluble or very slightly soluble in carbon tetrachloride, petroleum ether, ligroin and cyclohexanone. It is a contact and stomach poison with some fumigant action. It has penetrating effect also. Under natural conditions it is readily dehydrochlorinated to dichlorvos. It is a quick acting chemical effective against Lepidoptera, Diptera and Hemiptera. It has a lower order of toxicity to bees and it should not be used on apples until four weeks after blossom otherwise may result in leaf and fruit drop. It is also used in baits. Its acute oral and dermal LD_{50} for rat are 650 and >5000 mg/kg. Formulated as 80 % soluble powder, 5 % granular and 5 % dust. It is used in baits containing 100 g of active ingredient (soluble powder), 10 kg of bran, 500 g of sugar or 1 kg of molasses in 8 to 10 litres of water for the control of cutworms. Bait sprays consisting of the active ingredient and protein hydrolysate are useful for the control of fruit-flies. Granule is used for the control of borers of maize and sugarcane.

4.3.5 Carbamates

Carbamates are derivatives of carbamic acid and have an – OCON═ group in the molecule. Development of carbamate insecticides has been receiving the attention of chemists for the past 15 to 20 years as a result of which some are now on the market. The carbamates that were first marketed are isolan, a systemic insecticide, and dimetilan, a stomach poison, which belong to N,N-dimethyl-carbamates. These were followed by the N-methylcarbamates of which carbaryl has become one of the most widely used broad spectrum insecticides. The others include products like propoxur (arprocarb), methiocarb, Zectran, etc. Insecticides and acaricides are also found in carbamates such as aldicarb. Some may be found useful in the control of nematodes and snails. The carbamate esters inhibit acetylcholinesterase in insects and mammals.

The insecticidal carbamates are derivatives of carbamic acid and dithiocarbamic acid.

Derivatives of Carbamic acid

They are classified into three classes viz. heterocyclic carbamates, phenyl carbamates and oxime carbamates.

Heterocyclic Carbamates

Isolan: Isolan is a product containing l-isopropyl-3-methyl-5-pyrazolyl dimethylcarbamate or 1 -isopropyl-3-ethylpyrozolyl-(5) N,N-dimethyl carbamate. It is a systemic insecticide effective against aphids and has been used in fly baits. Its acute oral and dermal LD_{50} to rat being 12 and 35 to 60 mg/kg, respectively.

Pyrolan: Pyrolan is a product containing l-phenyl-3-methyl-5-pyrazolyl dimethylcarbamate. Its acute oral LD_{50} to rat is 50 to 90 mg/kg.

Dimetilan: Dimetilan is 2-dimethylcarbamoyl-3-methyl-5- pyrazolyl dimethylcarbamate and found use in fly baits. Its acute oral and dermal LD_{50} to rat are 25 to 50 and 600 to 700 mg/kg respectively.

Other compounds include Pirimicarb, Dimefan and Dimetan.

Phenylcarbamates

Carbaryl

Carbaryl is l-naphthyl N-methylcarbamate. Its insecticidal properties were first described by H. L. Haynes* and his associates and introduced in 1956. It is a white crystalline solid. The technical material is 95% pure. Its solubility in water is 0.004 %, and is soluble in solvents such as xylene, methyl isobutyl, ketone, petroleum ether and carbon tetrachloride. It is a non-specific insecticide effective against a wide spectrum of pests including those that are resistant to chlorinated hydrocarbon insecticides. It is a contact and stomach poison and has a longer residual action. Its acute oral and dermal LD_{50} to rat are 400 and >500 mg/kg respectively. Dust containing 2.5 % carbaryl is used in the control of human lice and dandruff and cattle lice. Ticks of cattle, sheep and dogs and mites and lice of poultry are controlled by 5% carbaryl dust. In the control of pests of crops it is effective against pests of cotton, red palm weevil on coconut, pests of vegetable crops, etc. Formulations are: Dusts containing 2.5, 5 or 10 % carbaryl, 85 SP, 50 WP, 24 % emulsive concentrate and 4 % granule. Granule containing 4 % each of carbaryl and gamma HCH is effective against pests of rice and sugarcane.

Propoxur

Propoxur is 2-isopropoxyphenyl N-ethylcarbamate. It is a white to cream-coloured crystalline powder with a mild phenolic odour. Its solubility in water is about 0.2 % but readily soluble in organic solvents. A broad spectrum insecticide effective in controlling household and public health pests. It is a contact and stomach poison, brings about rapid knock down and has a long residual action. Its acute oral and dermal LD_{50} to rat are 83 to 175

* *Contrib. Boyce Thompson Inst.*, 1957, 18 : 507

and > 1000 mg/kg respectively. Formulations are: 20 % EC, 1% or 2% aerosol and1% spray in hotels, bakeries, factory buildings, warehouses, storerooms, schools, military barracks, stables, ships, aircraft, etc. for the control of cockroaches, crickets, flies, etc.

Carbofuran

Carbofuran ($C_{12}H_{15}NO_3$) is 2,3-dihydro-2,2-dimethyl 7 benzofuranyl methyl carbamate. It is a white crystalline solid with slightly phenolic odour. It is noninflammable and unstable in alkaline media. It is a reversible cholinesterase inhibitor capable of causing systemic toxic effects when inhaled or ingested. Its acute oral and dermal LD_{50} to rat are 8.2 to 14.1 mg/kg and 10,200 mg/kg respectively. It is effective against sucking pests, thrips, mites and soil-inhabiting pests such as corn rootworms, flea beetle larvae, white grubs, maggots and nematodes. Established crop tolerances are 0.5 ppm in forage, 0.1 ppm in grain, and 0.2 ppm in rice and rice straw. Formulation available in India is 3% Gr.

Carbosulfan

Carbosulfan is 2,3-dihydro-2,2-dimethyl benzofuran- 7-yl (dibutylaminothio)-methyl carbamate. It is effective against a broad spectrum of pest species on various crops. It is metabolized in plants to carbofuran and 3-hydroxycarbofuran. Its acute oral and dermal LD_{50} for rat are respectively are 185-250 mg/kg and >2000 mg/kg. Its registered formulations are 25% DS and 25% EC. Seed treatment with 25DS 50 g/kg delinted seed of cotton effectively controls sucking pests up to 40 days after sowing. Foliar spray with 25% EC at 400-500 g a.i./ha controls the sucking pests on cotton.

Oxime Carbamates

These N-methyl carbamic acid derivatives are the esters of the oximes of aliphatic and cyclic aldehydes and ketones. They are reported to be effective against insects, mites and nematodes.

Aldicarb

Aldicarb, $C_7H_{14}N_2O_3S$, is (methylthio) propionaldehyde 0-1-(methyl-carbamoyl) oxime. It is a systemic insecticide, acaricide and nematicide, effective against a wide spectrum of insects and mites and nematodes. It is formulated as a 10 % granule intended only for soil application. In plants it is rapidly absorbed and oxidised to the principal toxicant aldicarb sulfoxide, which is further oxidised to the less toxic aldicarb sulfone. The rapid uptake of aldicarb and systemic movement of its metabolites in plant is attributed to their relatively high solubility in water. Its acute oral LD_{50} to rat is 6.2 mg/kg and dermal 3200 mg/kg. It was in use for the control of golden nematode of potatoes on the Nilgiris.

Methomyl

It is a product containing S-methyl-N- [(methylcarbamoyl) oxy] thioacetamidate. It is a white crystalline solid with a sulfurous odour. Its acute oral LD_{50} for rat is 17 mg/kg (male), 24 mg/kg (female); dermal (rabbit) >2000 mg/kg. It has broad spectrum control of insects of a wide variety of crops. It is effective against cabbage looper, imported cabbageworm and Diamondback moth and cotton bollworms at 300-450 g a.i./ha. Registered formulation in India is 40% SP.

Thiodicarb

Thiodicarb is Dimethyl N,N-(thiobis(methylimino)carbonyloxy)bis(ethanimidothioate). Empirical formula is $C_{10}H_{18}N_4O_4S_3$. It is an insecticide with ovicide action and active against major lepidopterous pests. Its acute oral LD_{50} for rat is 160 mg/kg; dermal (rabbit) >2000 mg/kg. As seed treatment rapidly gets translocated systemically through plants. Also acts as a moluscicide causing paralysis and death. It is registered as 75% WP and recommended at 0.75 kg a.i./ha for control of bollworms on cotton.

Oxamyl

Oxamyl is methyl N', N'-dimethyl-N-[(methyl-carbamoyl)oxy]-l-thiooxamidate. It is formulated as 25.2% EC and 10% granule. It is effective against insects, mites and nematodes and has systemic action. When applied to the foliage, gets translocated to the roots and controls nematodes in some crops. Its acute oral LD_{50} to rat is 5.4 mg/kg.

Derivatives of Dithiocarbamic Acid

Carbothion

It is Sodium N-methyldithiocarbamate. It is a nematicide and formulated as 40 % EC and the dosage is 250 to 1000 kg/ha applied three weeks prior to planting. Its nematicidal action is attributed to the breakdown product methyl isothiocyanate. Its acute oral LD_{50} to rat is 820 mg/kg.

4.3.6 Organic Sulphur Compounds

These are compounds, which are effective against mites on crops and ticks on animals and are called acaricides. A number of them are inactive against insects. Certain compounds are exclusively ovicides and may kill the newly emerged nymphs, the others kill all stages of mites. These are in general stable and possess long residual action and low mammalian toxicity.

Tetradifon

Tetradifon, $C_{12}H_6CI_4O_2S$ is 2,4,5,4 tetrachiorodiphenyl sulphone. It is a crystalline solid insoluble in water and its melting point is 148°C. It is stable in alkali and acid media, light and temperature. It possesses a very prolonged residual action. Its acute oral LD_{50} to rat is >5000 mg/kg; dermal LD_{50} to rabbit is 10,000 mg/kg. It is effective against all stages of mites. It is not toxic to bees and does not taint the treated plants if applied at concentrations of 0.1 to 0.2 %. The formulation 8% EC was recommended for the control of tea mites but presently its use in India has been withdrawn.

Propargite

Propargite is 2-(4-tert-butylphenoxy) cyclohexyl prop-2-ynyl sulfite. Empirical formula: $C_{19}H_{25}O_4S$. It is a light to dark brown liquid and miscible with organic solvents such as acetone, toluene, methanol, dichloromethane and hexane. It is an acaricide effective against mites on a wide range of crops and fruit trees. Its acute oral LD_{50} for rat is 2800 mg/kg; dermal (rabbit) >4000 mg/kg. It is relatively safer to bees and other beneficial insects. Propargite 57% EC has been found effective against mites on tea, chillies, apple, etc.

4.3.7 Synthetic Pyrethroids

Allethrin was the first synthetic analogue of pyrethrum developed in 1949 by Green and La Forge. The other compounds subsequently synthesised were furethrin, barthrin, tetramethrin, cyclethrin, resmethrin, bioresmethrin, etc. The following synthetic pyrethroid compounds have received greater attention in India.

Allethrin

Allethrin, $C_{19}H_{26}O_3$, is the common name for (*RS*) -3 -allyl-2 methyl-4 oxocyclopent - 2 enyl (*1RS*) -*cis, trans* chrysanthemate. It was first described by M. S. Schechter *et al.* in

1949 and introduced by Sumitomo Chemical Co. It has contact, stomach and respiratory action and brings about quick knockdown of flies and mosquitoes when applied in combination with synergists like piperonyl bitoxide. The acute oral LD_{50} for rat is 585- 1100 mg/kg; dermal for rat > 2000 mg/kg. Its registered formulations are 0.5%, coil, 2% and 4% mat, 0.5% aerosol and 3.6% L.

d-Allethrin

It is (*RS*) – 3 allyl - 2 methyl - 4 -oxocyclopent - 2 - enyl (*IR*) *cis, trans* chrysanthemate. It has been registered mainly as 2% and 4% mat and 1% coil for control of mosquitoes. Its acute oral LD_{50} for rat is female 900 mg/kg, male 2150 mg/kg; dermal for rabbit > 2000 mg/kg. Each mosquito mat, which is ready to use, contains 4% *d*-allethrin w/w. The mat is required to be heated in an electric heater device sold for the purpose. Consequent to the rise in temperature of the heater the insecticide is vapourised and vapours are released to the air for a period of seven to eight hours. For better results close the doors and windows for 30 minutes initially after switching on the device. The mat is to be changed every night. Products available are 0.1% coil – green or red, 0.5% coil, 0.2% coil and 2% + PBO 2% mat.

Alphacypermethrin or Alphamethrin

Alphamethrin, $C_{22}H_{19}C_{12}NO_3$, is a pyrethroid insecticide with contact and stomach action. It is effective against a wide range of chewing and sucking insects of agricultural crops, insects of public health and ectoparasites of animals. Acute Oral LD_{50} for rat is 64 mg/kg; dermal for rabbit > 2000 mg/kg. The formulation registered is 10% EC. It is recommended for control of cotton bollworms at 25-35 g a.i./ha. Alphamethrin 5% WP finds use in pubic health pest control.

Cyfluthrin

Cyfluthrin, $C_{22}H_{19}CI_2NO_3$, is Cyano (4-fluoro-3-phenoxyphenyl)methyl 3-(2,2-dichloroethenyl)-2,2 dimethylcyclopropanecarboxylate. It is a contact and stomach poison with rapid knockdown and long residual action. Controls many pests of crops, and pests of public health, veterinary and stored product importance. Acute oral LD_{50} for rat is 500 mg/kg; dermal for rat > 5000 mg/kg. Formulation registered is 10% EC and recommended at 12.5-18.0 g a.i./ha. For public health pest control 10% WP and 5% EW have been registered in India.

Cypermethrin

Cypermethrin is the common name for (*RS*) cyano- 3 -phenoxybenzyl (*1RS)-cis, trans* -3-(2,2 – dichlorovinyl)-2,2-dimethyl cyclopropanecarboxylate. The *cis/trans* ratios may vary with manufacturing process. M. Eliott *et al.* (1975) discovered it. It is a stomach and contact insecticide effective against lepidopterous larvae affecting various crops particularly bollworms and leaf eating caterpillars of cotton. Its acute oral LD_{50} for rat is 250 mg/kg (corn oil), 4123 mg/kg (aqueous suspension). It is relatively toxic to honey bees. Formulations: 10% EC and 25%EC. For household pest control cypermethrin 1% chalk, cypermethrin 0.1% aqueous HH and cypermethrin 0.11% + pyrethrum 0.02% + PBO 1% aerosol have been registered.

Cyphenothrin

It is (RS)á-cyano-3-phenoxybenzyl (1R)-cis,trans-chrysanthemate. Its acute LD_{50} for rat – oral 318 mg/kg (male), 419 mg/kg (female), dermal >5000 mg/kg. It is an insecticde for control of flying and crawling insects in household, industrial areas and outdoor use.

Deltamethrin

Deltamethrin is the common name for (*S*) S-cyano-3 phenoxybenzyl (*1R*)-*cis* - 3- (2,2 - dibromovinyl) - 2,2-dimethyl cyclopropanecarboxylate. M. Elliott *et al.* (1974) described it and it was introduced by Roussel Uclaf. It is an effective contact and stomach poison against a wide range of insects and recommended at a dosage varying from 12.5 to 15 g a.i./ha. It is stable on exposure to air and sunlight. It is also recommended for the control of mosquitoes and animal ectoparasites. Its acute oral LD_{50} for rat is 135 mg/kg and dermal for rabbits > 2000 mg/kg. It is toxic to fish and honeybees. Formulations are: 2.8% w/w EC (250 g a.i./litre), 0.02% spray, 2.5% Flow, 2.5% WP, 0.5% Chalk and tablet; deltamethrin 2.5% + *d*-allethrin 2% EC and deltamethrin 0.05% + allethrin 0.04% aerosol.

d-Phenothrin

It is 3-phenoxybenzyl (1R)-cis-trans-chrysanthemate. Its acute LD_{50} for rat – oral >10000 mg/kg, dermal >10000 mg/kg. It finds use in control of stored grain pests and flying and crawling insects in household and industrial locations.

Etofenprox

Etofenprox, $C_{25}H_{28}O_3$, is a non-ester pyrethroid introduced in 1987. It is a contact and stomach insecticide. Its acute oral LD_{50} for rat is 42880 mg/kg; dermal for rat > 2140 mg/kg. It is effective against pests of rice, particularly BPH and leafhoppers at 50 g a.i./ha. It is also effective against houseflies and cockroaches. Its registered formulation is 10% EC.

Fenpropathrin

Fenpropathrin is (RS) á-cyaano-3-phenoxybenzyl 2,2,3.3-tetramethyl-cyclopropanecarboxylate. It is yellow brown liquid or solid soluble in common organic solvents. Its acute oral LD_{50} for rat is 66 mg/kg; dermal (rabbit) >2000 mg/kg. It is an acaricide and insecticide effective against lepidopterous larvae, aphids, whiteflies, mites, etc. on various horticultural and agricultural crops. It also controls mosquitoes. Formulation is 2.4 EC.

Fenvalerate

Fenvalerate is the common name for (*RS*)- cyano - 3 - phenoxybenzyl (*RS*) - 2 - (4-chloro phenyl) - 3 methylbutyrate. It was first reported by N. Ohno *et al.* (1974). It is a contact insecticide effective against leaf-eating caterpillars and cotton bollworms. It is stable in sunlight and has longer residual toxicity. Also useful in the control of public health insects and animal ectoparasites. Its acute oral LD_{50} for rat is 300-630 mg/kg; in rabbits moderate skin and eye irritation has been observed. Formulations are: 20% EC and 0.4% DP. Effective against a wide range of pests at 60-75 g a.i./ha.

Lambda-Cyhalothrin

Lambda – cyhalothrin, $C_{23}H_{19}ClF_3NO_3$, chemically á-cyano-3-phenoxybenzyl 3-(2-chloro-3,3,3-trifluoro-prop-1-enyl)-2,2-dimethylcyclopropanecarboxylate is a 1:1 mixture of the (Z)-(1R, 3R), S-ester and (Z)-(1S,3S), R-ester. It is a contact and stomach insecticide and acaricide with quick knock-down and long residual action. Its acute oral LD_{50} for rat is 79 mg/kg (male), 56 mg/kg (female); dermal 632 mg/kg (male), 696 mg/kg (female). It is effective against a wide range of pests of agriculture and public health importance. Its registered formulations are 5% EC, 10% WP and 0.5% chalk. Formulation 5% EC recommended for control of pests of groundnut, rice, onion, etc. at 12.5-25.0 g a.i./ha.

Permethrin

Permethrin is 3-phenoxy benzyl (*1RS*) *cis, trans*-3(2,2,dichlorovinyl)-2,2 dimethyl cyclopropane-carboxylate. The ratio of *cis-trans* isomers may vary with manufacturing process. It was discovered by M. Elliot *et al.* (1973)*. It is a contact insecticide effective against a large number of insect pests particularly lepidopterous larvae at 100-150 g

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* *Proc . Br . Insectic . Fungic . Conf* . 7 th, 1973, **2:** 721.

a.i./ha. It also finds use in the control of ectoparasites of animals and public health and household pests. Its acute oral LD_{50} varies with the *cis/trans* ratio of the technical material. For 40:60 ratio the values are: oral for rat is 430 to > 4000 mg/ kg. Formulations are: 25 EC and 5% in smoke generator.

Prallethrin

Chemically it is (S)-2-methyl-4-oxo-3-(2-propynyl)-cyclopent-2-enyl (1R)-*cis-trans*-chrysan-the-mate. It is yellow to yellow-brown liquid miscible with most organic solvents. Its acute oral LD_{50} for rat is 640 mg/kg (male), dermal >5000 mg/kg. It is effective against flying and crawling insects in household. It finds use in aerosols, emulsifiable concentrate, mosquito coil/mat, vapouriser liquid, and oil liquid. Prallethrin 0.04% and 0.05% mosquito coils, Prallethrin 0.5% mat, 1% blue or red mat, 1.2% mat, 0.8% or 1.6% LV (liquid vapourizer) have been introduced.

4.3.8 Six-membered Heterocyclic Compounds

Certain compounds with six atoms in the ring are known to have specific biological activity and among them coumarin has been found to be a promising rodenticide. Derivatives of coumarin have blood anticoagulant properties and, therefore, when systematically introduced into their food they cause internal bleeding and death of the rodents.

Bromodiolone

It is a coumarin anticoagulant. Empirical formula $C_{30}H_{23}BrO_4$. Chemically it is 3-[3-(4'bromo [1,1'biphenyl]-4yl)-3-hydroxy-1-phenyl-propyl]-4-hydroxy-2H-1-benzopyran-2-one. It is registered as 0.25% concentrate bait, 0.005% ready to use bait and 0.005% ready to use bait cake. It is a single dose anticoagulant rodenticide and causes haemorrhage in the blood system. It ensures destruction of the insect in four to five days. The cake is to be placed near to burrow / places frequented by rats and no pre-baiting is necessary. No bait shyness is noticed.

Coumatetralyl

Coumatetralyl, $C_{19}H_{16}O_3$, is 3 (α-tetralyl) 4-hydroxycoumarin. It is more toxic to rats than warfarin and coumachlor. Powder containing 0.75 % active material is sprinkled in hiding places and on rat runways. One part of the powder may be mixed with 19 parts of bait material and used. It blocks prothrombin formation in the liver resulting in inhibition of blood coagulation. Multiple feeding is essential. No bait shyness is observed.

Coumachlor

Coumachlor is 3-(α-acetonyl) 4-chlorobenzyl)-4-hydroxycoumarin. It is also useful as a rodenticide. Registered as 0.5% concentrate bait and 0.025% ready to use bait.

Warfarin

Warfarin, $C_{19}H_{16}O_4$, is 3-(α-acetonylbenzyl)-4- hydroxycoumarin. It is used for the control of rats in baits as 0.025 % ready to use bait or 0.5% concentrate bait. The animal has to be fed with the poison at least for four or five times in the course of several days to obtain effective mortality of rats. It is an anticoagulant rodenticide. It causes internal bleeding by causing reduction of the prothrombin content of the blood.

4.3.9 New Classes of Compounds including Fermentation Products

In the recent years a number of new classes of compounds have been introduced for pest control and a number of them have been registered for use. Some such new compound which are under development and those which are registered in India are listed below. The Insect Growth Regulators (IGR) have been listed under the chapter Insect Growth Regulators.

Abamectin

An insecticide *cum* acaricide having a mixture containing ≥ 80 % avermectin B1a and ≤ 20% avermectin B1b. It has contact and stomach action. It is effective against mites and leaf miners on vegetables, citrus, etc. It stimulates release of γ-aminobutyric acid, an inhibitory neurotransmitter, which causes paralysis in insects. Acute oral LD_{50} for rat 300 mg/kg and dermal for rabbit > 2000 mg/kg. It is toxic to bees. No bioaccumulation in environment has been reported. Found effective against mites on roses in polyhouses and diamond back moth on cabbage. Formulation: 1.9 % EC.

Acetamiprid

Acetamiprid, $C_{10}H_{11}ClN_4$, is (E)-N^1-(6-chloro-3-pyridyl)methyl)-N^2-cyano-N^1-methyl-aceta-midine. The technical grade is a white powder soluble in acetone, methanol, dichlorome-thane and acetonitrile. Its acute oral LD_{50} for rat is 417 mg/kg (male), 314 mg/kg (female). It is effective against sucking pests of crops like cotton at 15-20 g a.i./ha. Formulations are 20 SP and 3 EC.

Alanycarb

It is a carbamate insecticide chemically known as Ethyl (*Z*)-*N*-benzyl-*N*-{[methyl(1-methylthioethylideneamino-oxycarbonyl)amino]thio}-β-alaninate. Pure product is a colourless crystalline powder. It is suitable for foliar spray, soil treatment or seed treatment. Its acute oral LD_{50} for rat is 440 mg/kg; dermal for rabbit >2000 mg/kg. It is found effective against cotton bollworms at 500 g a.i./ha.

Amitraz

It is N'-(2,4-dimethylphenyl)-N-[[(2,4-dimethylphenyl)imino]methyl]-N-methylmethanimidamide; N-methylbis(2,4-xylyliminomethyl)amine. It belongs to the class Triazapentadiene. It is a white crystalline solid soluble in common organic solvents. Its acute oral LD_{50} for rat is 650 mg/kg; dermal >1600 mg/kg. It is an acaricide and insecticide. It controls psylla, whiteflies and tetranychid and eriophyid mites. Its formulations are EC and WP.

Bifenazate

Its chemical name is Hydrazine carboxylic acid, 2-(4-methoxy-[1'1-biphenyl] –3-yl)-1 methylethyl ester. It belongs to the class carbazate. It is an acaricide for ornamental plants in greenhouse, shadehouse, nursery and field. It is effective against a variety of species of mites and all life stages of *Tetranychus* spider mites. As it is safer to predacious mites and beneficial insects it is ideally suited for Integrated Pest Management and resistance management. It has rapid knock-down and long residual action. It is a product of Uniroyal Chemical Co., the trade name being Floramite.

Cartap

Cartap, $C_7H_{16}ClN_3O_3S_2$, is commonly known as Cartap hydrochloride. The chemical names are: *S,S* - 2-dimethylaminotrimethylene) bis(thiocarbamate) hydrochloride (or) 1,3-bis(carbomylthio)-2-(N,N-dimethylamino) propane hydrochloride. Its insecticidal properties were reported by M. Sakai *et al.* in 1967. Its acute LD_{50}: oral (rat) male 345 mg/kg, female 325 mg/kg; dermal (mice) > 1000 mg/kg. It is systemic with stomach and contact action. It acts on the central nervous system by ganglionic blocking action resulting in paralysis, cessation of feeding and death due to starvation. It is effective against rice stem borer and leaf folder, sugarcane shoot borer, cabbage diamond back moth, etc. at dosages 500-1000 g a.i./ha. Its registered formulations in India are 50 SP and 4 G.

Chlorfenapyr

It is a pyrrole compound. Chemically it is 4-bromo-2-(4-chlorophenyl)-1-ethoxymethyl-5-trifluoromethylpyrrole-3-carbonitrile. Its acute oral LD_{50} for rat is 441mg/kg (male), 1152 mg/kg (female). It is an insecticide and acaricide effective on crops such as roses in polyhouses, cotton, citrus, etc. at 100-300 g a.i./ha. Its formulation is SC. It is safer to *Orius insidiosus* and *Cotesia marginientris.*

Clofentezine

It is 3,6-bis(2-chlorophenyl)-1,2,4,5-tetrazine. It belongs to the class Tetrazine. The technical grade material is a pure odourless, magenta coloured crystalline solid. Its acute oral LD_{50} for rat is >5200 mg/kg; dermal >2000 mg/kg. It is an acaricide with ovicidal action. It is found effective against mites on roses in polyhouses. It is usually formulated as a suspension concentrate.

Dazomet

Chemically it is Tetrahydro-3, 5- dimethyl - l,3,5, thiadiazine - 2 - thione. It is a broad spectrum and soil sterilant introduced by BASF under the trade name Basamid granular containing dazomet 98%. The technical grade is a crystalline solid, white-slightly grey in colour. Its spectrum of activity is related to control of soil-borne diseases (fungi and bacteria), nematodes, soil insects, weeds and rhizomes and tubers of perennial weeds. It is non-toxic to bees. It decomposes in water to yield fumigant vapour. Its oral LD_{50} is 640 mg/kg, dermal > 2000 mg/kg. It is recommended for effective management of root-knot nematodes and weeds in FCV tobacco nurseries in Karnataka as a suitable alternative to methyl bromide fumigation. Prior to application of granule apply recommended quantity of FYM in the nursery. Water the seed-beds daily for a week to facilitate hatching of root-knot nematode eggs and also to induce germination of weed seeds. Broadcast dazomet granule uniformly @ 30 g/m and incorporate the microgranules into the soil to a depth of 10 cm. Irrigate the beds sufficiently and cover it with polyethylene sheet, sealing it all round. Remove the cover after 15 days and loosen the soil, aerate the beds for three to five days and then take up sowing. This effectively controls root-knot nematodes, fungi, nut grass, etc. and provides healthy transplants.

Dienochlor

It is Bis(pentachloro-2,4-cyclopentadien-1-yl); decachlorobis (2,4-cyclopentadien-1-yl). The technical grade is a tan crystalline solid. Solubility is slight in aliphatic hydrocarbons and acetone; moderately soluble in aromatic hydrocarbons. Its acute oral LD_{50} for rat is 3160 mg/kg; dermal (rabbit) >3160 mg/kg. It is an acaricide for the control of mites on indoor floral plants such as rose. The formulaltion is 50% EC.

Emamectin benzoate

It is a semi-synthetic avermectin derived from fermentation of avermectin B (abamectin); mixture of 4" epimethylamino-4" deoxy-avermectin B1a and B1b benzoate salts. The technical grade is a white to off-white powder. Its LD_{50} for rat- oral 1516 mg/kg, dermal >2000 mg/kg. It is an insecticide for use in cotton. Formulation is EC.

Fenazaquine

It is registered in India as 10% EC and found effective against mites on tea. Also effective against coconut eriophyid mite at 200–250 ml/100 litres water or root feeding at 10 ml/palm.

Fipronil

Fipronil, $C_{12}H_4C_{l2}F_6N_4OS$, is chemically (5-amino-1-(2,6-dichloro-4-(trifluoro-methyl)phenyl)-4-(1,R,S)-(trifluoromethyl)su-1-H-pyrasole-3-carbonitrile. It belongs to the class Fiproles. It is an insecticide and acaricide effective against pests of rice in India. Acute oral LD_{50} for rat 100 mg/kg; dermal for rat > 2000 mg/kg. Its registered formulations in India are 0.3% Gr. and 5% SC. It is effective against pests of rice at 50-75 g a.i./ha. Fipronil 0.05% gel formulation for control of household pests has been developed.

Imidacloprid

Imidacloprid, $C_9H_{10}ClN_5O_2$, is chemically1-(6-chloro-3-pyridylmethyl)-*N* nitroimidazolidin - 2 - ylideneamine. It belongs to the class Chloronicotinyl. Acute oral LD_{50} for rat 450 mg/kg; dermal for rat > 5000 mg/kg. It is a systemic insecticide with stomach and contact action. Controls sucking insects, soil insects, rice water weevil etc. It is used as a seed dressing or foliar/soil treatment for control of pests of cotton, rice, etc. The 75WS formulation is treated with cotton seed at 10 g/kg seed which provides protection against whitefly and leafhopper up to 40 days after sowing.

Indoxacarb

It belongs to the new class of chemistry – Oxadiazine. Chemically it is (S)-methyl 7-chloro-2,5-dihydro-2[[(methoxy-carbonyl) [4-trifluoromethoxy)phenyl]amino]carbonyl]-indeno[1,2-e] [1,3,4]oxa-diazine-4a(3*H*)-carboxylate. Molecular wt. 527.84; Empirical formula $C_{22}H_{17}ClF_3N_3O_7$. Technical is white powder. Its acute oral LD_{50} for rat is 3619 mg/kg (male), 751 mg/kg (female); dermal (rat) >5000 mg/kg. It is effective against diamondback moth on cabbage and *Helicoverpa armigera* on cotton at 75 g a.i./ha. On cotton it is recommended to be applied at square and flower formation stage, boll formation stage and boll maturity stage. It is useful in Insecticide Resistance Management (IRM) programmes. Formulation 14.5% SC.

Pymetrozine

It belongs to the class Pyridine azomethines. Chemically it is 1,2,4-triazin-3(2H)one,4,5-dihydro-6-methyl-4-[3-pyridinylm-ethylene)amino]. Its acute LD_{50} for rat – oral > 5000 mg/kg, dermal >2000 mg/kg. It is effective against scales and aphids at 100-300 g a.i./ha.

Pyridaben

It belongs to the class Pyridazinine and chemically it is 2-tert-butyl-5-(4-tert-butylbenzylthio)-4-chloropyridazin. Its acute oral LD_{50} for rat is 82-1350 mg/kg; dermal >2000 mg/kg. It is a white crystalline material soluble in methylene chloride; relatively soluble in acetonitrile and ethanol. It is an acaricide and insecticide. It controls mites on ornamentals and field crops. It is also effective against psyllids, leaf hoppers and white/flies. Formulations EC, SC and WDP.

Spinosad

This is an insecticide of natural origin, containing a mixture of two components derived from fermentation technology produced by *Saccharopolyspora spinosa*, a species of actinomycete. It comprises of spinosyn A + spinosyn D. Its acute oral LD_{50} for rat is >5000 mg/kg. It is formulated as 45 SC and is active against *Helicoverpa armigera*, leaf hopper, aphid and white/fly on cotton at 75–100 g a.i./ha. For diamond back moth on cabbage 2.5% SC has been found effective at 15.0–17.5 g a.i./ha.

Thiomethoxam

It belongs to Nionicotinoid group. Seed treatment with 70 WS at 4 g/kg seed or foliar spray of 25 WG at 25-50 g a.i./ha is effective against sucking pests of cotton and pest complex of rice.

5. Fumigants

A fumigant is a gaseous poison used to kill insects, nematodes and rats, and its application is limited to live plants or products in tight enclosures or to soil. The gas enters the insectan body through spiracles in the case of larvae, pupae and adults, and the eggs through the chorion and brings about death. A fumigant that vaporises readily at room temperature is the most useful. An essential requirement of a soil fumigant is that the vapour should emerge slowly. An ideal fumigant is determined by its relative effectiveness, cost, penetrating power, safety to human beings, living animals, plants and germinating seeds, reactivity with household furnishings, flammability etc. Fumigants are employed to control diverse varieties of stored product pests, pests on household articles, etc. Soil fumigation is done to eradicate soil dwelling insects and nematodes. Live plants are fumigated for controlling subterranean pests. As a quarantine measure imported plants are also fumigated.

In any fumigation operation the first principle to be observed is to safeguard human lives and only trained personnel with necessary protective appliances should be entrusted with the work. The enclosure to be fumigated must be as nearly air tight as possible and it is better to avoid windy or cold weather. There should be provision for ventilation after fumigation. If living plants are fumigated, accurate dosage must be used in addition to scrupulously following the proper time for exposure and ventilation, and the temperature should be at an optimum between 14-27°C. It is desirable to have the treatment done at night or in darkness. If no live plants are involved, the fumigant is used slightly in excess and the materials are exposed as long as convenient. The temperature is to be between 21 and 38°C. Food substances containing moisture may get poisoned after fumigation.

The dosage for fumigation is expressed in terms of lb/1000 cu. ft. or oz/1000 cu. ft. or g/m^3 and an effective fumigant should bring about 99 % destruction of the insect population which is referred to as the critical (Ct) value. The Ct value is the product of the concentration of the gas per unit volume multiplied by the duration of the exposure. For a successful programme, the following information will be necessary:

(i) The volume of enclosed space; and

(ii) The rate of release of fumigant vapour.

If the exposure period is shorter the concentration of the gas needed will be more. The sorption of the gas by the material fumigated affects the dosage and the critical value of the fumigant. And further, the rate of sorption is dependant on the moisture content of the material. The dosage recommended is intended for a standard period of exposure to achieve useful results, and in live plants it is limited to the amount that could be tolerated without any apparent phytotoxic effects. Tent fumigation is adopted for fumigating trees, tents being relatively airtight into which a hose introduces the gas. Vacuum fumigation is done using gas in a partial vacuum to enhance penetration and to save time.

The following are some fumigants which find use in control of storage pests.

5.1 Hydrogen Cyanide or Hydrocyanic Acid: HCN

This is the most extensively used fumigant, originally employed for the control of the cottony cushion scale in the USA. It is a volatile, colourless liquid with a bitter almond odour and a specific gravity of 0.699 at 20°C. The gas has specific gravity of 0.943 and is highly inflammable and explodes in mixtures above 5.6 % or above 64 g/m^3. Under normal atmospheric pressure the gas is not able to penetrate and a partial vacuum fumigation is employed. Metals like gold, brass, nickel, etc. are tarnished by HCN, which could be removed by promptly rubbing with polishing cloth or prevented by prior application of grease. HCN is liberated when sodium or potassium cyanide is treated with sulphuric acid or on exposure of calcium cyanide to moist atmosphere. Cyanogas contains 40 to 50 per cent CaCN and the gas is liberated slowly. It is used in fumigation of burrows of rats. The plants/trees to be fumigated should not be watered for some hours previous to fumigation. The gas is not compatible with Bordeaux mixture and hence should not be applied on plants before or after fumigation. HCN is one of the most deadly gases and at higher dosages or if exposed too long it may kill plants. The gas becomes toxic to insects and warm blooded animals as it combines with iron atoms of cytochrome oxidase. Only experienced persons should be allowed to handle fumigation. Gas masks should be used. For general fumigation the dosage is 10-16 g sodium cyanide (98 % pure), 20-30 ml sulphuric acid and 40-60 ml water per m^3. For fumigating live plants the dosage is 12-25 g sodium cyanide, 20-40 ml sulphuric acid and 40-80 ml water for 100 m^3.

Carbon Bisulphide

Also known as carbon disulphide. It was first employed in France to control pests of stored grains. It is a colourless liquid with a disagreeable odour due to traces of hydrogen sulphide. It has a specific gravity of 1.263 at 20°C and vapour pressure of 360 mm Hg at 25°C. It is slightly soluble in water but soluble in organic solvents, highly inflammable and explosive in mixtures above 1 % in air. It is used for the control of stored product pests in godowns, and pests of clothes, dress and draperies. It has also been used to control wood borers, bots and intestinal larvae, which are given gelatine coated capsules. Emulsions are used in controlling soil insects and nematodes. Fumigation is done at temperatures ranging from 75 to 90°F. The dosage is 10 lb of carbon bisulphide per 1000 cu. ft of space or 2 to 3 gallons per 1000 bushels of grain for 36 to 72 hr. It does not affect the milling qualities of the grain, germination of seeds and does not leave residues on seeds. The gas possesses good penetrating power. When used as a soil fumigant it is known to stimulate growth of many kinds of crops. Commercial mixtures of 20 % CS_2, 80 % CCl_2, and a trace of SO_2 have a greatly reduced fire hazard and the dosage is 15 to 20 lb/1000 cu. ft. of space or 3 to 5 gallons/1000 bushels of grain. The fumigant is highly phytotoxic.

Methyl Bromide or Bromomethane

It is one of the most widely used fumigants. It has a low boiling point and at ordinary temperatures it is a colourless and odourless gas. Its vapour pressure is 1580 mm Hg at 25°C and the gas is not inflammable. The specific gravity is high, 1.732 at 0°C and this is the commonly used fumigant. It requires a longer period of exposure as it kills the insects slowly. A dosage of 24–32 g/m^3 with an exposure period of 48 hours is advocated for stored grain pests. For termites, powder post beetles, etc. tents with a dosage of 32–64 g/m^3 is employed. In plant quarantine centres fumigating live plants, nurseries, etc. fumigation is done with 16-32 g/m^3. However, some plants are adversely affected by methyl bromide. For soil fumigation 4.7 ml/sq. ft. is used in combating insects, weeds and nematodes. The fumigant is a dangerous cumulative poison to warm blooded animals; the nervous system is affected and lethal results are produced. A gas mask with cannister should be worn always by the technician employing the fumigant. Picric acid (2 %) is added to cylinders of methyl bromide, which causes irritation of eyes in case the gas persists in the area of fumigation. A halide detector lamp shows a blue flame if the gas is present.

Chloropicrin or Trichloronitromethane

It is a tear gas of limited use in controlling insects. Its specific gravity is 1.651 at 20°C and vapour pressure 24 mm Hg at 25°C. It is a colourless to yellowish liquid stable at room temperature. It is slightly soluble in water and soluble in organic solvents. It possesses good penetrating ability, non-inflammable, corrodes metals slightly but does not bleach or tarnish. In the control of household and stored product pests, the dosage used is 16-48 g/m^3. Chloropicrin should not be used on growing plants or germinating seeds. It is useful as a soil fumigant against some soil forms and nematodes. The low volatility of the compound makes it difficult to remove the gas and in routine fumigations of inhabited areas this is not employed.

Carbon Tetrachloride

Carbon tetrachloride is a colourless liquid with specific gravity 1.595 at 20°C and vapour pressure of 114.5 mm of Hg at 20°C. It is almost insoluble in water but soluble in organic solvents. The gas has a specific gravity of 5.31, is not inflammable or explosive and possesses pungent chloroform-like odour. It is comparatively less toxic to insects and slow acting and is so not very much used. When used with carbon bisulphide or ethylene dibromide it reduces fire hazard. It increases the volatility and distribution of fumigants like methyl bromide, ethylene dichloride and chloropicrin.

Ethylene Dichloride or 1,2 Dichlorethane

This is a colourless liquid with specific gravity of 1.257 at 20°C, vapour pressure of 78 mm Hg at 25°C. The gas is inflammable between 6 and 16 % in air and has a specific gravity of 3.4. It is slow acting and destruction of insect takes place from one to three days after exposure. Most germinating seeds are not affected, but is phytotoxic. Generally, it is used with carbon tetrachloride as a fumigant.

EDCT or Ethylene Dichloride-Carbon Tetrachloride Mixture

It is a general fumigant mixture consisting of three of ethylene dichloride and one of carbon tetrachloride by volume. Such a mixture, either as gas or as liquid is free from fire hazard. It could be transported or stored in cans. This, when poured or sprayed on to the material, vapourises and fumigates. The temperature is usually kept at 24°C. The dosage is 160–300 g/m^3 in airtight stores for 24 hours. In fumigating chests, wardrobes, etc. double the above dosage is recommended.

Ethylene Dibromide or 1.2-Dibromomethane

Ethylene dibromide is a colourless liquid with specific gravity of 2.172 at 20°C and vapour pressure of 11 mm Hg at 25°C. The gas has a specific gravity of 6.5 and is non-inflammable. It is used at 8 g/m^3 for destroying fruit fly larvae in fresh fruits and vegetables and this does not affect the plant materials. As a soil fumigant it is used for the control of wireworms, whitegrubs, etc. at a dosage of 18 to 72 lb/acre in 20 gallons petroleum naphtha injected into the soil. As it is toxic to many plants the soil should be aerated thoroughly. It is formulated as liquid, granule and even as capsule. The liquid is injected into soil at 15 to

20 gallons/hectare and the 35 per cent granular material is dibbled in the soil at a depth of 15 to 20 cm at a spacing of 30 x 30 cm at 300 lb/acre for the control of nematodes.

DD is a mixture of two-thirds 1,3-dichloropropene and one-third of l,2-dichloropropane or propylene dichloride. It is injected into the soil for the control of wire-worms, centipedes and nematodes. The liquid is injected into the soil at a depth of 15 to 20 cm at a spacing of 30 × 30 cm as pre-plant treatment at least two weeks before planting because of its highly phytotoxic nature. It is not being used in India.

Phosphine

Phosphine or hydrogen phosphide is widely used to fumigate grain, flour and cereals in godowns. The commercial products available as tablets or pellets or plates are aluminium phosphide or magnesium phosphide, which on contact with moist air release phosphine. The gas is highly toxic to all stages of insects.

Paradichlorobenzene

Paradichlorobenzene is a white, crystalline material vapourising slowly (vapour pressure 1 mm Hg at 25° C) into non-inflammable gas with ether-like odour. Its specific gravity is 5.1. It is only slightly soluble in water. It is used as a soil fumigant for controlling apple woolly aphis. Carpet beetles and clothes moths in homes and museum pests like dermestids are controlled by the gas. This was also used against red palm weevils. A dosage of 12 g/m^3 is suggested.

Naphthalene

Naphthalene is a white crystalline material with specific gravity of 1.517 at 15°C. It vapourises slowly with vapour pressure 0.08 mm Hg at 25°C. It is inflammable when mixed with air. It is slightly soluble in water, but readily dissolves in organic solvents. It is used against clothes moths, carpet beetles, etc. at 1 g/m^3. It is available as moth balls or moth flakes.

6. SYSTEMIC INSECTICIDES

Systemic insecticides find use in the control of insects infesting animals and plants.

6.1 Systemic Insecticides for Animals

In animals systemic insecticides have been used for the control of internal parasites such as screw-worm larvae, cattle grubs and helminths and external parasites such as ticks, mites, lice, stableflies, etc. The insecticide used should not be harmful to the host animal but should be toxic to the pest species only. These compounds are either applied topically or administered orally to the animals. The toxicant is found to move in the tissues of the animal in quantities sufficient to bring about kill of the parasites. The slow destruction of the toxicant in the tissues is achieved by enzymatic action and an animal is recommended for slaughtering or for milching after a safe period of about 60 days from the time of application or administration of the toxicant. Two systemic insecticides used widely for the control of animal parasites have been crufomate (Ruelene) and fenchlorfos (Ronnel).

6.2 Systemic Insecticides for Plants

A systemic insecticide is one in which the toxicant penetrates into all plant tissues and gets transported in insecticidal quantities from the point of application in apical direction and possibly with a weak downward flow restricted to single leaves but not in the whole plant, and displays endo-therapeutic effects over a sufficiently long period. Some chemicals like nicotine, HCH, parathion, etc. possessing penetrating ability exhibit translaminar action and are not generally translocated and stored as in true systemics. If some translocation is observed it would be in very small quantities to those applied.

The chief requirements for an effective and safe systemic compound are:

(i) High intrinsic pesticidal activity,

(ii) Adequate liposolubility of the toxicant for absorption by the plant system,

(iii) Sufficient water-solubility to enable translocation,

(iv) Stability of the compounds or its metabolites for sufficiently long period to exercise residual effect, and

(v) Susceptibility to decomposition into non-toxic products in the plant system.

The main advantages of systemic insecticides are:

(i) The toxicant is not subjected to weathering as it penetrates into the plant system and remains in it sufficiently long to exercise residual effect;

(ii) As the toxicant is translocated in apical direction, fresh plant growth formed subsequent to application needs no treatment for a reasonable period; and

(iii) Due to selective action exhibited by systemic toxicants, beneficial insects like parasitoids and predators and pollinating insects like bees are not destroyed.

The systemic insecticides are applied variously such as treatment of seeds before planting, application of granular formulation of the toxicant in seed furrows before sowing, implantation of encapsulated material about the roots or into the stem, drenching the soil, broadcasting the material in standing water in rice fields, direct application or injection of concentrates to the stem or trunk, and foliage spray application.

Absorption: Though the entire plant surface and seeds can absorb the toxicant, the most important organs of uptake are the roots and leaves. The type of formulation, dosage, characteristic of plant species, part treated, edaphic and other ecological factors govern the degree of absorption of the toxicant. The largest quantities of absorption of the toxicant by roots takes place from aqueous solutions and the uptake decreases in proportion to the increase in the content of absorptive constituents, especially humus as in demeton, disulfoton, phorate, etc. In the control of aphid on potato, granular dimethoate and menazon are reported to be more effective in wet than in dry soils, whereas disulfoton and phorate are equally effective in both. However, even with the former two the effects of moisture is small and is probably the result of several different interacting factors. Selective action in absorption of the toxicants through roots is exhibited by plant species. The uptake is greater with increased physiological activity of the plant under relatively high temperature with adequate moisture.

Leaf absorption takes place in several ways, the young leaves being more absorptive than old leaves and generally the absorption is greater on the undersurface of leaves than on the upper surface. For highly liposoluble materials the most important route of entry is the cuticle rather than the stomata. The surface of leaf veins, being composed of thin-walled cells, favours easy penetration. The retention of spray droplets as also the range of time taken for absorption are important. Phosphamidon and monocrotophos are absorbed in a few hours as against a few days in the case of thiono isomer of demeton and Schradan. Temperature and light are important factors in controlling absorption through leaves and the relative response of the plants varies with plant species.

Bark of stem and branches of woody plants like coffee and citrus absorb systemic insecticides like Schradan, demeton, and dimefox, and it appears that in woody plants the absorption through trunk is more efficient than through roots. Monocrotophos, dicrotophos and phosphamidon are also similarly absorbed in herbaceous plants.

Soaking of seeds in the chemical or coating the seeds with it or application of the chemical at sowing are some methods by which absorption of the active ingredient by seeds is achieved. The absorption is rapid when seeds are soaked in the chemical. Absorption by seeds is dependent on the method, type of seed and the lipoid and water-solubility of the toxicant. In the case of seed soaking or coating, while absorption through cotyledons takes place, part of the toxicant may diffuse out of the seed into the soil where it can be absorbed by the developing roots.

Translocation: In this process the toxicant absorbed is transported along the transpiration stream towards plant parts of intense metabolic activity resulting in varying levels of temporary accumulation. The parent compound or its metabolites should be more water-soluble for efficient translocation. Demeton thiol isomer having a solubility range of 2000 to 3900 ppm is rapidly translocated than thiono isomer having a solubility range from 60 to 1250 ppm. Better translocation of disulfoton and phorate is achieved on oxidation to more soluble sulfoxide and sulfone derivatives. The toxicant absorbed by roots is transported upward and gets distributed to shoots chiefly with the transpiration stream, the xylem. There may also be some of localised lateral diffusion into phloem. The speed of translocation increases with increase in transpiration, which in turn is influenced by high temperature coupled with adequate humidity.

In foliar application, the movement of the systemic insecticide in a treated leaf occurs from the base to the apex and a very slow migration in the opposite direction may occur through diffusion from cell to cell to the leaf base. Recent evidences suggest that downward flow of systemic phosphates in phloem from treated to untreated leaves occurs in very low amounts of insignificant therapeutic value or does not take place at all. Therefore, an even distribution of a systemic insecticide over the whole plant cannot occur in case of partial treatment of foliage.

In bark or stem implantation treatment the active ingredient absorbed is translocated in the upward direction. Downward transport of metabolites through phloem is negligible and is mainly a resultant of radial transfer from xylem.

Storage and Metabolism: The organophosphorus (OP) systemic compounds translocated in appreciable quantities are stored in distinctive sites in plants and are subjected to oxidative and hydrolytic metabolism and dehydration. Consequently, activation and detoxification will result. Similar reactions occur in the bodies of the insects and mammals.

The organophosphorous systemic compounds, based on their behaviour in the plant system, are classified as: Endolytic systemic compounds, and endometatoxic systemic compounds. In the former, 98 % of the parent compound exists in its original form when ingested by the pest species, until it is decomposed by the plant and the toxic action results from enzymatic metabolism within the pest species, for example is Schradan. In the latter, the toxicants are transformed in the plant either partially or wholly into other toxic compounds which are also toxic when ingested by pest species before they are decomposed by the plant, e.g. some phosphates, the thiono and thiol isomers of demeton, methyl demeton (phosphorothionate and phosphorothiolate), phorate, dimethoate, disulfoton (phosphorothiolothionate). The rate of metabolism of endometatoxic compounds within plants is accelerated by higher temperatures due to the acceleration in the physiological activity of the plant. The ultimate systemic effect in most cases is the result of a combination of oxidative and hydrolytic process comprising of the evolution of relatively unstable products which are generally more polar and thus more water-soluble than the parent compound to promote easy translocation.

The primary cause of organophosphorus poisoning in insects is attributed to inhibition of the cholinesterase enzyme system. Organophosphates also block other enzymes, viz. aliesterase in insects, which are important in detoxification process.

Some organophosphorus systemic compounds such as Schradan and phosphamidon are more water-soluble and exhibit very little affinity for the body lipids, which account for their relatively low dermal toxicity.

Among inorganic compounds, sodium selenate is said to be systemic. After World War II organic systemic insecticides have been synthesised in large numbers. Systemic organophosphates belong to phosphates, phosphorothionates, phosphorothiolates, phosphorothiolothionates, etc. A few systemic carbamates include carbofuran and aldicarb.

Systemic insecticides are used for the control of sucking insect pests, midges, leafminers, borers, mites, etc.

7. COMPATIBILITY OF SPRAY CHEMICALS

When two chemicals are brought together in a single spray mixture, due to reaction, a compound differing from either parent may be formed. On application, a knowledge of the effects of such compounds on the plants is essential to avoid improper use. The incompatibility in such cases may be:

(1) Chemical incompatibility : Different compounds are formed due to reaction of various chemicals as in synthetic organic compounds with an alkaline material.

(2) Phytotoxic incompatibility: The component parts though by themselves are not injurious to the plants and do not show any chemical reaction when mixed, the mixture causes injury to plants.

(3) Physical incompatibility: In this case the chemicals used to change their physical form to one that is unstable and hazardous for application.

8. FACTORS INFLUENCING EFFECTIVENESS OF INSECTICIDES

The various factors that influence effectiveness of pesticides are:

1. The mode of entry of the chemical into the body of the insect: Adding an oil to a spray mixture makes it lipophilic and thus it is able to penetrate through the cuticle and increase its toxicity. Stomach poisons are absorbed in the midgut.

The spray enters or penetrates the tracheal system easily if its surface tension is lowered by addition of a material.

2. The developmental stages of an insect larvae and nymphs are often more susceptible than the other stages.

3. Effectiveness of insecticides is affected by environmental conditions. Generally quick acting poisons are more effective at high temperatures but get detoxified inside the body of the insect early. Slow-acting poisons are effective at lower temperatures. Fine mists produced in concentrate spraying may dry off under conditions of low relative humidities. Water soluble sprays may be washed off by rains. Sunlight is responsible for the break-down of the residues of certain insecticides. Air current affects dusting and spraying operations resulting in uneven coverage and especially so when applied with aircraft.

4. The condition of the plant is another important factor. In case of plants having waxy leaves the spray solution may run off and this can be corrected by additions of a wetting agent. When there is heavy or thick foliage the coverage of the insecticide may not be even.

◆ Chapter 90

Botanical Insecticides

In recent years misuse or overuse or indiscriminate use of pesticides in crop protection has caused serious environmental problems, pest resurgence, pest resistance to pesticide, toxicity to non-target beneficial species and those handling them. It has, therefore, become necessary to search for alternative means, which can minimise the use of synthetic chemicals. In this context use of botanical pesticide/ natural plant products is emerging as a major thrust area in integrated pest management and research has been intensified. Many plant products have been reported to possess insecticidal activity, repellency to pests, antifeedancy, insect growth regulation, etc. It has been reported that around 866 plant species have activity against insect species. The botanical pesticides have the following advantages over synthetic pesticides.

a) Possess low mammalian toxicity and thus constitute least/ no health hazards and environmental pollution.

b) No risk of developing resistance if used in natural forms.

c) Less hazardous to non-target organisms.

d) Not known to cause resurgence of pest species.

e) Non-phytotoxic to crop plant.

Following are some important plant species, which have been explored or can be explored for their potential in crop protection.

1. *Acorus calamus* Linn. (Araceae) (Sweet flag)

In India this plant is grown primaraily in Jammu & Kashmir, Manipur, Mysore and Northern Himalayas. It is reported to have insecticidal, insect repellent, antifeedant, attractant and chemosterilant properties against insects in storage and field. Rhizome/root powder and its extracts are effective against insect pests such as *Rhyzopertha dominica, Sitophilus oryzae, Tribolium castaneum, Latheticus oryzae,* and *Sitotroga cerealella* of paddy and *Callosobruchus chinensis* of pulses in storage. Sweet flag oil is also reported to be toxic to these pests. The oil has shown chemosterilant effect in *Trogoderma granarium* and *C. chinensis.* Ethyl ether extract of the rhizome exhibited attraction of both male and female of Mediterranean fruit fly *Ceratitis capitata* and the Oriental fruit fly *Bactrocera dorsalis.* Four components of the oil are methyl eugenol, β-asarone, acoragermacrone and agarylaldehyde, which are responsible for the attraction of fruit flies.

2. *Allium sativum* Linn. (Amaryllidaceae) (Garlic)

This plant is commonly grown in northern and central states of India. Bulb extract and garlic oil possess insecticidal and insect repellent properties against insects infesting grains in storage and crops in the field. The active component from garlic extract was identified in 1971 as 'allitin', a mixture of diallyl di- and trisulphides, which inhibits cholinesterase activity in insects and effective against insects in stored paddy. In 1980 the active compound 1-3, diphenyl thiourea was extracted which was effective against the rice weevil *S. oryzae.* Its unpleasant odour and low persistence are undesirable traits.

3. *Annona reticulata* Linn. (Annonaceae) (Bullocks heart or Custard apple)

It is a perennial tree found in West Bengal, Assam, Khasi Hills and South India and has edible fruit. Its bark, leaf, fruit and seed exhibit insecticidal, antifeedant and repellent activities against a number of agricultural insect pests infesting grains in storage as well as crops in the fields. Seed extract contains the insecticidal components such as glycerides of hydroxylated unsaturated acids. In 1971 'anonaine', a toxic alkaloid from *Annona* spp. was reported to have insecticidal activity. Anonaine occurs along with other relative alkaloids viz., roemerine, nuciferine, recticuline and 6-methoxy, 7-hydroxy aporphine, which are also toxic to insects.

4. *Annona squamosa* Linn. (Custard apple, Sweet soap, Supper apple)

It is a perennial shrub or small tree found throughout India. Its roots, leaf, fruit and seed extracts in water, ether and alcohol and their powders have shown insecticidal, antifeedant and repellent activities against insect pests in storage and in the field. Its seed oil when sprayed on rice crop was reported to effectively reduce the survival of *Nephotettix virescens* and transmission to rice tungro virus, and survival of the rice leaf folder *Cnaphalocrocis medinalis*. Spray of leaf extract reduced the survival of the whitefly *Bemisia tabaci* and also transmission of yellow mosaic virus (YMV) in mung bean crop. Its insecticidal component is the alkaloid, anonaine.

5. *Azadirachta indica* A. Juss. (Meliacea) (Neem or Margosa tree)

This is a perennial tree distributed in tropical, subtropical, semi-arid and arid zones. It is found throughout India and a highly explored tree species. It possesses medicinal, insecticidal, insect repellent, antifeedant, growth regulant, nematicidal and antifungal properties. Its insecticidal properties against a wide range of pests in storage as well as in the field is well known. Dried powder of neem leaves admixed with sorghum or wheat grains afforded protection against stored grain pests. Leaf extract of neem also showed insecticidal activity against important field pests such as *Plutella xylostella, Hypera postica, Aproaerema modicella, Spodoptera litura,* etc. The desert locust, *Schistocerca gregaria,* avoids feeding on neem leaves. Neem leaves proved to be an attractant to the adults of the beetles *Holotrichia serrata, H. consanguinea* and *H. insularis,* whose grubs damage seriously sugarcane roots. This has facilitated collection and destruction of the adults during dusk. Neem leaf bitters (NLB) have been found to reduce the oviposition and development of the green leaf hopper *Nephotettix virescens* and the brown plant hopper *Nilaparvata lugens* on rice.

Neem seed/kernel extract also showed insecticidal activity against storage pests. It also showed antifeedant activity against the desert locusts *Locusta migratoria* and *Schistocerca gregaria, Amsacta moorei, Spodoptera litura, Epilachna varivestis,* etc. Neem oil also proved to be useful against a large number of insect pests in storage (1 to 2% neem oil w/w) and in the field (0.2 to 0.4%, 1 to 2%, or 5% or 10% neem oil). Neem kernel powder as well as cake have also shown insecticidal activity.

From the neem seed extract and oil a number of components have been identified of which azadirachtins, deacetyl-salannin, salannin, nimbin, epinimbin and meliantriol possess biological activities such as insect repellent, antifeedant, growth inhibitor/regulator and insecticidal. Azadirachtins, a group of C_{26} terpenoids, are structurally similar to the insect ecdysones. Azadirachtin was first reported in 1986 from neem seeds, which exhibited feeding inhibitory effect in the desert locust *S. gregaria.*

Azadirachtin

Extracted from the kernels of the neem tree *Azadirachta indica.* Chemical name is dimethyl [2aR-[2aα, 3β, 4β (1aR*, 2S*, 3aS*, 6aS*,7S*,7aS*), 4aβ,5α,7aS*,=8β(E),10β,10aα,10bβ)]-10-(acetyloxy) octahydro- 3,5- dihydroxy-4- methyl-8-[(2-methyl-1-=oxo-2-butenyl)oxy]-4-(3a,6a,7,7a-tetrahydro-6a-hydroxy-7a-methyl-2,7-methanofuro[2,3-=b] oxireno[e]oxepin-1a(2H)-yl)-1H,7H-naphtho [1,8-bc: 4,4 a-c'] difuran-5,10a(8H)-= dicarboxylate. Molr. wt. 720.7; Molr. Formula $C_{35}H_{44}O_{16}$. It is an yellow-green powder with a strong garlic /sulfur odour. Acute oral LD_{50} for rat >5000 mg/kg, acute dermal for rabbit >2000 mg/kg. It disrupts insect moulting by antagonizing the insect hormone ecdysone and is also an antifeedant to some insects.

Formulations of neem products: Several agrochemical companies have either introduced or testing different formulations of neem based products and some have been registered in the country for use.

Replin is a mixture of oils of neem, kharanja, castor, mahuwa and gingelly, and azadirachtin constitutes 300 ppm in it. It is effective against field crop pests at 1-2%. Margosan O constitutes neem oil fraction and effective as 2% solution. Neemark constitutes neem seed oil with azadirachtin in the crude form. Welgro is a product of neem kernel powder. Neemrich is a dichloroethane extract effective as 0.1% spray against *Spodoptera litura.* Achook is a water soluble powder (WSP) that contains 0.03% azadirachtin, azadiradion, nimbocinol, and ebinimbocinol as active principles. It has been found effective against *Helicoverpa armigera* and *Earias vittella* on cotton.

6. Pyrethrins

Pyrethrum was used as an insecticide at about 1800 in the Transcaucasus region of Asia. The six insecticidal constituents present in extracts of the flowers of the plant *Pyrethrum cinerariaefolium (=Chrysanthemum cinerariaefolium)* (Asteraceae) are collectively known as pyrethrins and comprise esters of the natural stereoisomers of chrysanthemic acid viz., pyrethrin I, cinerin I and jasmolin I, and the corresponding esters of pyrethric acid viz., pyrethrin II, cinerin II and jasmolin II. Most commercial extracts contain 20-25% pyrethrins. Generally the ratio of pyrethrin: cinerin: jasmolin is reported to be 71:21:7. Pyrethrins are extracted commercially from crops grown in Kenya, Tasmania and Tansania. The extract is refined using methanol or supercritical carbon di oxide and the crude extract is dark brown. Pyrethrum flowers contain 0.924 to 1.178% pyrethrins and 90% of the pyrethrins occur in the achenes of the flower head.

It is a contact insecticide and causes paralysis initially and death follows. Pyrethrum is formulated as dusts, emulsions, solutions and aerosols. The pyrethrin content ranges from 0.05 to 0.10%. It is useful against a wide range of insect and mite pests of public health, stored grains, animal houses and on pets and farm animals. Normally it is combined with the synergist piperonyl butoxide, which inhibits detoxification. Due to its lack of persistence and instability in the presence of light it does not find acceptance in agricultural pest control. Its acute oral LD_{50} for rat: male 2370 mg/kg, female 1030 mg/kg; dermal for rat >1500 mg/kg.

Pyrethrum 2% dust and Pyrethrum 1% EC have been registered in India for use against insect pests of vegetables. For household pest control the formulations used are: pyrethrum 0.05% + synergist 0.05% HH, pyrethrum 0.2% RTU, pyrethrum 0.05% + lindane 0.05% RTU, pyrethrum 0.02% + lindane 0.02% + synergist 0.5% RTU, pyrethrum 0.02% + malathion 0.05% + synergist 0.5% RTU, pyrethrum 0.05% + lindane 0.05% RTU, pyrethrum 0.05% + malathion 1% aerosol, pyrethrum 1% aerosol, pyrethrum 0.2%HH, and for public health pyrethrum 2% EC and pyrethrum larvicidal oil 0.2% EC.

A number of synthetic pyrethroids have been synthesized by alteration in their structures and configurations, which have photo stability and insecticidal activity. Allethrin was the first synthetic pyrethroid developed.

7. *Derris elliptica (Wall.) Benth.* (Fabaceae) (Derris or Tuba-root)

This is a perennial shrub grown in tropical and subtropical regions. Root of the plant is an effective poison for fish and insects. As early as 1848 it was known as an insecticide. The root contains the derris resin, which constitutes rotenone (25%) and related components called rotenoids. It is a stomach poison to insects. Poisoned insects exhibit a steady decline in oxygen consumption followed by paralysis and death. It also has acaricidal activity. It is chemically (2*R*,6a,*S*,12a*S*)-1,2,6,6a,12,12a-hexahydro-2-isopropenyl-8,9-=dimethoxy chromeno[3,4-b]furo[2,3-h] chromen-6-one. Molecular. wt. 394.4; Molecular. formula $C_{23}H_{22}O_6$. Acute oral LD_{50} for rat: 132-1500 mg/kg.

Rotenoids or rotenone are known to be present in species of leguminous plants and the principal economic plants are *D. elliptica* and *D. malaccensis* (contain 5 to 9 % rotenone) in the Far-East and *Lonchocarpus utilis* and *L. uruca* (contain 8 to 11 % rotenone) in South America. Rotenone is the chief among the toxic constituents obtained from the roots of these plants, the other naturally occurring rotenoids being elliptone, sumatrol, malaccol, toxicarol, deguelin, tephrosin, etc. The roots are dried and powdered and mixed with three to seven parts of a diluent such as talc, clay, gypsum, etc. to be used as a dust containing 0.05 to 0.10 per cent rotenone. Dusts are reported to be useful in the control of external parasites of animals, such as fleas and lice and also for the control of ox warbles. The commercially available crystalline rotenone is used for moth proofing and does not stain the material.

8. *Lobelia excelsa* (Companulaceae)

This plant is found on the Western Ghats in South India at an elevation of 2000 m. The leaves are cured in shade and chopped, and 1 kg of the leaves are soaked in water for about a day. The infusion is filtered and the filtrate made up to 20 litres and 60 g of soap is added. It was reported to be effective against aphids on snakegourd and cowpea, tingids on brinjal and mites on castor and lady's finger.

9. *Madhuca indica* J. F. Gmel. (=*Bassia latifolia)* (Sapotaceae) (Mahua)

This is a perennial tree found in Central and South India. Its oil when admixed with grains gave protection against storage pests viz., *R. dominica* and *S. oryzae*. Its leaf, bark and seed extracts also exhibited insecticidal and repellent activities in pulse beetle *C. chinensis*. Application of mahua cake to soil reduced incidence of grubs of *Holotrichia insularis* in chillies. Its bark and seed extracts gave protection against *Crocidolomia pavonana* and *Spodoptera litura*. Seed kernel extract minimised the incidence of the whitefly *Bemisia tabaci* and yellow mosaic virus in mung bean. Its seed oil affected the survival of rice green leaf-hopper, BPH and the white backed plant hopper. Spray application of 2% oil thrice at 15 day interval minimized the incidence of the citrus leaf miner *Phyllocnistis citrella*.

10. *Melia azedarach* Linn. (Meliaceae) (China-berry, Pride of India, Dharak, Persian lilac)

This is a perennial tree found in tropical and subtropical areas. Its leaf, bark, fruit and seed extracts and kernel powder and its oil cake have been reported to exhibit repellent, antifeedant, insecticidal and growth inhibiting activities against storage pests and major agricultural pests. Its 2% leaf powder admixed with basmati rice afforded protection against storage pests. Its active components from leaf extracts are a derivative of 'paraisin' and 'meliantin', the latter reported to possess anti-locust activity. The active component 'meliantriol-I' is present in seed oil. Azadirachtin has been isolated from its leaf and fruit extracts.

11. *Nicotiana tabacum* Linn. (Solanaceae) (Tobacco)

Though tobacco was used in insect control as early as 1763, its principal alkaloid was discovered only in 1828. At least 15 species of *Nicotiana, Duboisia hopwoodii* and *Asclepias syriaca* are known sources of nicotine; the chief sources being *Nicotiana tabacum* and *N. rustica*. Twelve alkaloids have been isolated from tobacco and the alkaloid nicotine constitutes 97% of the total alkaloids. Other alkaloids possessing insecticidal activity are nornicotine, neonicotine or anabasine, nicotyrine and metanicotine, of which the last two are comparatively less toxic to insects. Nicotine is obtained from leaves and stems of waste tobacco by steam distillation or solvent extraction. Nicotine in leaves of *N. tabacum* amounts to 2 to 5%, whereas it is very low or negligible in other parts. The alkaloid content is high from 5 to 20% in *N. rustica.*

Nicotine is a non-systemic insecticide having predominantly respiratory action, and slight contact and stomach action. It decomposes relatively quickly in the presence of light and air. Chemical name is: (*S*)-3-(1-methylpyrrolidin-2-yl)pyridine. In its pure form it is a colourless liquid soluble in water and in most organic solvents; when exposed to air it darkens and becomes more viscous. As a nerve poison it is highly toxic to insects. It is toxic to man by skin contact and inhalation. Its acute oral LD_{50} for rat 50-60 mg/kg; dermal for rabbit 50 mg/kg.

The commercial product is nicotine sulphate containing 40% alkaloid. It was patented in 1908. It is relatively safe and readily water soluble. The standard dosage rate has been 1 part of the material in 500 to 1000 litres of water by weight. In India it was mainly used for the control of cardamom thrips. Tobacco decoction is prepared by boiling 1 kg of tobacco waste in 10 litres of water for half an hour or steeping it in cold water for a day, and the infusion so obtained is made up to 30 litres. Addition of soap at 14 g to 4.5 litres of the infusion will improve its wetting, spreading and killing properties. This is useful in the control of aphids and thrips. Nicotine sulphate 40% solution and 10% DP have been registered in India for export only.

12. *Pongamia glabra* Vent. (Fabaceae) (Pongamia, Kharanjia)

It is a common tree found in coastal India and its root, leaf, flower, seed and fruit extracts in alcohols, their dried powders, seed oil, and oil cake show insecticidal, antifeedant and repellent activities against pests of storage and field crops. Oil at 1% w/w protected cowpea in storage against *C. maculatus.* Pongamia cake applied to soil protected tobacco against the ground beetle *Mesomorphus villiger* in nurseries, and root grubs (*H. insularis)* in chillies and (*H. consanguinea*) in groundnut. Its oil has been reported to be effective against green leaf hopper, leaf folder, BPH and WBPH on rice. The active components constitute 'karanjin' which shows juvenile-mimetic activity and antifeedant activity.

13. *Ryania speciosa* Vahl. (Flacourtiaceae)

It is a native of South America and found in South India. Ryania is obtained from the roots and stems of the plant and its most important alkaloid is 'ryanodine'. It is both a contact and stomach poison, less toxic to mammals than rotenone, more stable and possesses a longer residual action. It has been used for the control of lepidopterous larvae, thrips, etc. Its acute oral LD_{50} for rat is 750 to 1000 mg/kg.

14. *Schoenocaulon officinale* A. Gray (=*Sabadilla officinarum*) (Liliaceae) (Sabadilla)

This is an annual herb found in Mexico, Central and South America. Its active components extracted from bulb and seed contain two to four % of a crude mixture termed 'veratrine' and the alkaloids toxic to the insects in the mixture are 'cevadine' and 'veratridine' which are contact and stomach poisons. The compounds are also highly toxic to mammals and may cause eye irritations and violent sneezing. It has been reported to be effective against lepidopterous larvae, lygaeid bugs, grasshoppers, human lice, etc.

15. *Tephrosia candida* (Roxb.) D. C. (Fabaceae) (White tephrosia)

It is a perennial gregarious shrub found in India. Its seed extracts have been found effective against *Crocidolomia pavonana, Plutella xylostella, Spodoptera litura,* etc. The active components are 'tephrosin' and 'rotenone'. *Tephrosia purpurea* Linn. is a common species in India and its root and leaf extracts have insecticidal and antifeedant activities. The root extract is reported to have the component 'isoflavone' which has antifeedant activity to *Spodoptera litura*.

16. *Thevetia nerifolia* (Apocynaceae)

A native of South America the plant is commonly found in gardens and occasionally found to grow wild near towns and villages in India. It is a small tree with yellow flowers and some-what rounded angular fruits. The kernels possess insecticidal properties. Mashed kernels soaked in water at 15 to 30 g in 10 litres of water and with an equal quantity of soap added was reported to be effective against aphids, whiteflies, thrips, etc. and at higher concentrations against leaf-eating caterpillars.

17. *Vitex negundo* Linn. (Verbenaceae) (Indian Pivet, Chinese chaste tree)

A perennial shrub/tree found throughout coastal states, Bihar and North Eastern regions. Its branch, leaf and seed extracts and seed oil show insecticidal, repellent, juvenile hormone mimetic and antifeedant activities against a wide range of storage pests and lepidopterous larvae. The active components of *Vitex* spp. are viticosterone-E, iridoides, and ecdysones, which show juveno-mimetic activity in insects. The active component from leaf extract of *V. negundo,* 2-heptatriacontanone, inhibits oviposition in stored grain pests such as *S. cerealella, R. dominica* and *S. oryzae*.

◆ Chapter 91

Insect Growth Regulators

The need for new insecticides having both novel modes of action and with useful environmental effects cannot be over emphasised. Juvenile hormone analogues as insect growth regulators fulfill these criteria and many compounds with high juvenile hormone activity have been designed and tested against insects pest. Since the presence or absence of the insect juvenile hormone regulates embryogenesis, metamorphosis, reproduction, diapause, caste/morph determination and even influences sex determination, disruption of these processes is an important defense strategy. The juvenile hormones when applied to developing insects show deranged development showing several external deformities such as formation of supernumerary larvae, larval-pupal or pupal-adult intermediates, all of which result in mortality in a few days. Sometimes adults emerge out of treated larvae, but they fail to mate successfully and cannot lay eggs. The metabolic degeneration of natural JH occurs by enzymatic action of JH esterase. Some of the commercialised JH analogues are methoprene and hydroprene. Recent development of juvenoids fenoxycarb and pyriproxyfen have been found to have increased stability and biological activity. These are applied exogenously as sprays or mixed with insect diets and are known to have sterilising activities, besides their action as ovicides or larvicides. Methoprene has been used in the control of mosquitoes, flies, ants, fleas and so on. A mimic of methoprene, called Kinoprene, has been found to be useful against homopterous insects. Fenoxycarb has been used in the control of several fruit pests of apples, pears and even against *Helicoverpa* armigera in cotton where ovo-larvicidal efficacy was seen.

Many synthetic JH compounds have been available in recent years such as Juvocimene I & II from *Ocimum basilicum* possessing high JH activity. Juvodecimene from *Macropipa* sp. was seen to be effective against the large milk weed bug *Oncopeltus fasciatus.* In India the compounds 'bakuchiol' from *Psoralea corylifolia* and 'karanjin' from *Pongamia glabra* have been isolated. Of interest is a JH-III compound from *Cyperus iria,* which resulted in the juvenalisation of a grasshopper. While most of these products are active, it is clear that JH acts too late to prevent damage, since the immature stages are quick enough to cause damage. The important advantage is that the population of the concerned insect can be minimised, if the juvenoids are applied to the last larval nymphs which may be unable to mate and reproduce. It is here that the UV stable JH analogues such as fenoxycarb and pyriproxyfen herald adequate opportunities as crop protection agents.

The discovery of potential JH antagonists led the way to further intensive work on anti-juvenile hormone compounds called *precocenes.* Two active compounds were isolated from *Ageratum houstonianum,* identified as Precocene I & II. They induced precocious metamorphosis and sterilization, and as they rapidly penetrated the insect cuticle, they were useful in topical treatment. Mode of action of precocene treatment was cytotoxic to the corpora allata, which caused cell death and invasion of the allata by connective tissue. They have been called the 'fourth generation' pesticides. The precocenes induce a variety of physiological and behavioural changes including precocious metamorphosis of the immature stages, sterilisation of adult females, etc. Of interest is the fact that topical application of these compounds shortens the life cycle, resulting in diminished feeding, so that there is less crop damage.

Moulting Hormone Analogues

The moulting hormone produced by the prothoracic glands, called ecdysone, is responsible for normal moulting, growth and maturation of insects. While 20-hydroxy-ecdysone is the moulting hormone, others like 26-hydroxy-ecdysone are also known, and interestingly enough ecdysone-like compounds are also known to occur in numerous plants belonging to the ferns or Pteridophytes and Gymnosperms and some Angiosperms. The ecdysones- Ponasterone A from *Podocarpus* sp. and ecdysterone and Inokosterone from *Achyranthes* sp. as well as ecdysone and ecdysterone from *Pteridium aquilinium* and *Polypodium vulgare* were the firsts to be recognised in plants and since then several hundred plant species were found to possess different ecdysteroids. Increased titres of ecdysone or moulting hormone results on exogenous application of moulting hormone analogues resulting in moulting promotion and death of insects. Interestingly compounds with antiecdysone activity also occur in some plant species and these show inhibitory effects on the development of various insects. 'Plumbagin' from *Plumbago capensis* and 'azadirachtin' from *Azadirachta indica* have been shown to have anti-ecdysone effects, besides 'ajugarin' from *Ajuga* spp. Plumbagin caussed inhibition or delay in ecdysis as it directly acts on the prothoracic glands inhibiting the production of ecdysone. While the juvenility of azadirachtin is well known, there is evidence that it directly acts on corpus cardiacum causing disturbances in ecdysteroid titres.

Interfering with the moulting is a strategy and insect moulting inhibitors such as benzoylphenyl ureas have been known to interfere in moulting of Lepidoptera. Their effect is to generally interfere with moulting and cuticle synthesis. Disruption of feeding and embryonic development are also known. Important benzoylphenyl ureas available as chitin inhibitors in crop protection include diflubenzuron (Dimilin 25 WP), teflubenzuron (Nomolt 50 EC), flufenoxuron (Cascade 10 EC), chlorfluazuron (Atabron 5 EC) and triflumuron. Triflumuron at 0.01% and diflubenzuron at 0.02% caused 100% mortality to the Babul defoliator *Euptroctis lunata* larvae within 20 days of application in Pakistan. In India, diflubenzuron at 75-100 g a.i./ha was found effective against *Crocidolomia pavonana* on radish. Diflubenzuron at 300 g a.i./ha provided control of larvae of *Helicoverpa armigera* on chickpea three days after application. Flufenoxuron and chlorfluazuron both at 60 g a.i./ha were effective seven days after application against *H. armigera* on gram. Lufenuron 5 SC and diflubenzuron 25 WP are effective against larvae of *Plutella xylostella* on cabbage.

Benzoylphenyl Ureas: Following are some insect growth regulators derived out of benzoylphenyl ureas.

Buprofezin

Buprofezin, $C_{16}H_{23}N_3OS$, is 2-*tert*-butylimino-3- isopropyl - 5 - phenylperhydro - 1,3,5 - thiadiazin -4– one. Oral LD_{50} for rat > 2000 mg/kg; dermal for rat >5000 mg/kg. It has contact and stomach action. Effective against mealybugs, whiteflies, scales, planthoppers, etc. The eggs laid by treated insects are sterile.

Chlorfluazuron

It is 1-[3,5-dichloro-4-(3-chloro-5-trifluoromethyl]-2-pyridyloxyphenyl]-3-(2,6-difluoro-benzoyl) urea. The technical grade chemical are colourless crystals and its LD_{50} for rat is >8500 mg/kg. It is effective against lepidopterous pests of cotton and other crops.

Diafenthiuron

Diafenthiuron, $C_{23}H_{32}N_2OS$, is 1, *tert* butyl -3 - (2,6-di-isopropyl - 4 - phenoxyphenyl) thiourea. Oral LD_{50} for rat 2068 mg/kg; dermal for rat > 2000 mg/kg. It is an acaricide/ insecticide having contact and stomach action and some ovicidal action. It is effective against whiteflies, aphids, leafhoppers, diamondback moth, etc. Safe to the beneficial insects.

Diflubenzuron

Diflubenzuron, $C_{14}H_9ClF_2N_2O_2$, is 1-(4-chlorophenyl)-3 - (2,6 - difluorobenzoyl) urea. Oral LD_{50} for rat > 4640 mg/kg and dermal for rabbit >2000 mg/kg. It is effective against most leaf feeding larvae at 25-75 g a.i./ha and at 50 – 150 g a.i./ha against cotton bollworms. Non-toxic to predators and bees. Diflubenzuron 25% WP formulation is registered in India. Diflubenzuron is also used in control of fly larvae by topical treatment of the upper layer of the breeding medium at 20-40 g 25WP in water to cover 10 m^2 of surface area and repeated after two to three weeks. This is ideal for minimising housefly nuisance in poultry units. It is also used for the control of larvae of mosquitoes, biting midges and gnats. The dosages of 25 WP recommended for mosquito larval control for 100 m^2 of surface area are: 1-2 g for clear surface water and 2-4 g for polluted surface area; 4 g for 1000 in closed systems with standing water.

Lufenuron

Lufenuron, $C_{17}H_8Cl_2F_8N_2O_3$, is (*RS*)-1 [2,5-dichloro-4-(1,1,2,3,3,3 - hexafluoropropoxy) phenyl] - 3 -2,6-= difluorobenzoyl urea. Oral LD_{50} for rat > 2000 mg/kg; dermal for rat > 2000 mg/kg. It controls beetle grubs, lepidopterous larvae, fleas on pets and cockroaches. Formulation is 10%EC. At 30-60 g a.i./ha is effective against DBM on cabbage.

Novaluron

Novaluron, $C_{17}H_9ClF_8N_2O_4$, is effective against larvae of insects belonging to the order Lepidoptera, Coleoptera, Homoptera and Diptera. Its acute oral and dermal LD_{50} for rat is >5000 mg/kg. Formulation is 10% EC or SC. It is effective against cotton bollworms and DBM on cabbage at 50-100 g a.i./ha.

Teflubenzuron

It is 1-(3,5-dichloro-2,4-difluorophenyl)-3-(2,6-difluorobenzoyl)urea. Technical is white to greyish crystalline solid and its acute oral LD_{50} for rat is >5000 mg/kg; dermal > 2000 mg/kg. Effective against lepidopterous and coleopterous larvae and larvae of mosquito and fly.

Triflumuron

It is 2-chloro-N-[[[4-(trifluoromethoxy)phenyl]amino]carbonyl]benzamide. The technical grade chemical is a colourless powder and its acute oral and dermal LD_{50} for rat is >5000 mg/kg.

Other Classes of PGRs are:

Flufenoxuron

Flufenoxuron, $C_{21}H_{11}ClF_6N_2O_3$, is 1-[4-(2- chloro-α,α,α trifluoro-p-tolyloxy)-2 fluoro-phenyl]-3-(2,6 -difluorobenzoyl) urea. It belongs to the class Acylurea. Acute oral LD_{50} for rat > 3000 mg/kg; dermal for rat >2000 mg/kg. It is effective against a wide range of insects. Its 10% EC formulation at 75–100 g a.i./ha is effective against cotton bollworms.

Pyriproxyfen

Pyriproxyfen is 4-phenoxyphenyl *(RS)*-2-(2pyridyloxy)propyl ether. The technical grade chemical consists of colourless crystals. Its acute oral LD_{50} for rat is >5000 mg/kg; dermal (rabbit) >2000 mg/kg. Effective against a wide range of pests particularly scales and white/flies on cotton and citrus.

Tebufenozide

It is N-tert-butyl-N'-(4-ethylbenzoyl)-3,5-dimethylbenzohydrazide. Its acute oral LD_{50} for rat is >5000 mg/kg; dermal >5000 mg/kg. It is an insecticide against lepidopterous larvae and useful in forestry pest control as it maintains the natural populations of beneficial and predatory and parasitic insects.

◆ Chapter 92

Principles of Toxicology of Insecticides

The term toxicology is commonly used in the medical and veterinary fields wherein food and organs are analysed for toxic substances in cases of poisoning by chemicals. In the field of agriculture, it is related to the application of toxicants on animals.

In toxicology work it is possible to access the response of an organism to a given treatment in a variety of ways. By means of the probit and the dose metameter a linear equation could be calculated by which the relationship between mortality and concentrations of the toxicant to which the organism is exposed could be arrived at. In 1952* Finney has given the methods of computation. The concentration required to bring about 50% mortality is known as median lethal dose, LD_{50}, which forms the general criterion for the acute toxicity of a solid or liquid compound. The median lethal dosage is the amount of the toxicant required to kill 50% of a test population and is expressed in terms of milligrams of the substance of toxicant per kilogram body weight (mg/kg) of the animal, usually rat, when treated orally. As the test animal is usually rat and sometimes rabbit it is also referred to as the mammalian toxicity. The acute oral LD_{50} values for rat in case of a few chemicals are as follows; potassium cyanide 1, phorate 3.7, methyl parathion 14-24, phosphamidon 28, phosalone 135, fenitrothion 250, malathion 2800, etc. The amount of toxicant required to be placed on the skin to cause death of 50% of test population is referred to as acute dermal LD_{50}. The acute oral and dermal LD_{50} values for rat for the various chemicals are furnished under the respective chemicals dealt with elsewhere in this book. It must be understood that higher the value of LD_{50}, lesser is the toxic nature of the chemical. In the case of insects, the LD_{50}, value is expressed in terms of micrograms of the toxicant per gram body weight of the insect. The toxicity of a poison shows astonishing variation to

* Finney, D.J. 1952 *Probit Analysis,* Cambridge University. Press, Cambridge

different species of insects and therefore tests may be required against each species to assess its usefulness in pest control.

Acute toxicity refers to the toxic effect produced by a single dose of a toxicant whereas chronic toxicity is the effects produced by the accumulation of small amounts of the toxicant over a long period of time. The single dose in the latter case would produce no ill effect.

The term median lethal concentration, LC_{50}, is expressed in terms of percentage of the toxicant required to cause 50% kill of the population of a test animal. It is usually determined by a Potter's Tower Test and probit analysis.

The term I_{50}, refers to the concentration of a toxicant required to inhibit 50% of the enzyme (usually cholinesterase) of a test organism. It is determined under *in vitro* conditions. The values indicate the potential toxicity of organophosphates and carbamates which are potent enzyme inhibitors The term RL_{50}, i.e. Residual Life 50%, commonly referred to as half life of a chemical, indicates the time required for half of the initial deposit to dissipate.

1. BIOASSAY OF INSECTICIDES

Crop protection chemicals are evaluated in the field for their efficacy and performance under conditions of maximum variation in degree of infestation, variety, climatic conditions, etc., and this involves repeating the trials over a number of times and seasons, elaborate recording of observations and high cost in addition to the process of evaluation being slow. But it is essential to eliminate the variable as far as possible and assess the inherent toxicity affecting the biological activity of the compounds using live organisms. This involves laboratory investigations wherein the variable factors tested are the amount of the toxicant to which the organism is exposed and the time of exposure. Therefore, bioassay refers to the study of response of the individual organism exposed to the toxicant.

Bioassay is very easy to perform. It is simple, sensitive, and reliable and does not require any sophisticated equipment. In the field of agricultural entomology bioassay is useful for comparing the efficacy of various insecticides (LD_{50}, LC_{50}, etc.) and in residue analysis. In bioassay, a variety of sensitive organisms are used. These include *Drosophila melanogaster, Musca domestica, Bracon brevicornis, Tribolium castaneum,* etc., which can be multiplied under laboratory conditions. For a more sensitive detection photomigration method using mosuqito larvae or suspension method using water flea *Daphnia* sp. is being employed. Other methods followed are direct feeding method and dry film method. All these methods involve two steps, viz., construction of a standard dosage mortality curve and bio/determination.

Bioassay can be carried out using *Drosophila melanogaster* as the test organism and adopting dry film method for estimating residues present in products at various periods after application of the chemicals.

Potter Spraying Tower: In the 1930s Charles Potter realised the need for accurate and reproducible laboratory bioassay techniques, to relate the amount of insecticide applied to the resulting effect. He designed an apparatus appropriate for the atomised sprays and deposits used in his stored product studies. He improved the bioassay techniques and developed an apparatus, which could spray insecticide formulations on to a 9 cm diameter target with extreme accuracy and reproducibility. The target could consist of a surface on which insects were kept prior to spraying or on which a residual deposit was required. This apparatus refined over years, known as the Potter Spraying Tower or Potter's Tower, is still used in research laboratories throughout the world.

For flying and crawling insects like cockroaches, mosquitoes and houseflies persistence studies are carried out on different types of surfaces such as glass, wood, mud and cement, which are sprayed with the test insecticide, and on residual film on these surfaces the insects are exposed for 30 minutes and then shifted to recovery chambers for 24 hours, after which the mortality count is made. The satisfactory level of mortality of insects would be more than 90%. The residual toxicity is evaluated at different intervals.

Peet Gredy Chamber

Evaluation of space spray against flying insects is conducted in Peet Gredy Chamber as per standard ISI specification 1824. Mats/Coils are also evaluated in Peet Gredy Chamber for knockdown effect. Aerosols are to be evaluated inside a standard room as per WHO tech. report series No. 206.

2. INSECTICIDE RESIDUES

Most of the food we eat, although treated with agricultural chemicals, contains no residues. But the possibilities of harmful residues in food is clearly of concern to the public. When a pesticide is applied to a crop or the soil it starts to be broken down by the action of light, air, microorganisms and the metabolism of the plants. In a practical situation in certain crops several months can elapse between application of a pesticide and eventual harvest and thus no pesticide residues at all are detectable. In case a pesticide could give rise to a residue, pre-harvest intervals are stipulated on labels approved by the registration authorities to give the pesticide time to break down.

Before being consumed many food/material are stored and/or processed which also reduces residues. Many countries have legislation to regulate the levels of pesticide residues in food material and is guided by the concepts of 'Acceptable Daily Intake' (ADI) and Maximum Residue Levels (MRLs) promoted by the United Nations.

Acceptable Daily Intake (ADI) of a chemical is the daily intake, which, during an entire lifetime, appears to be without appreciable risk, on the basis of all the facts known at the time. It is expressed in milligrams of the chemical per kilogram of body weight. Long-term feeding studies are conducted in animals to establish the highest dose, in milligrams per kilogram of body weight, at which no effect at all is observed i.e. no observed adverse effect level (NOAEL). For humans the ADI is calculated in mg/kg of body weight, generally taken as an average of 60 to 70 kg. It is set at a safe level of at least 100^{th} of the NOAEL noted in the most susceptible test species. This is derived from the assumption that man is 10 times as sensitive as the most sensitive species and the most sensitive man is 10 times more sensitive than the norm.

Maximum Residue Level (MRLs) are estimated from globally generated pesticide residue data, obtained using appropriate good agricultural practice. Pesticide residue is any specified substances in food, agricultural commodities, or animal feed resulting from the use of a pesticide. The term includes any derivatives of a pesticide, such as conversion products, metabolites, reaction products, and impurities, considered to be of toxicological significance.

To avoid serious inconsistencies in MRLs between countries, the Codex Alimentarius Commission of the UN FAO has set up a coordinating committee, which reinforces national guards and provides even more consumer protection in international trade.

Good Agricultural Practice in the use of pesticides is the officially recommended or authorised use of pesticides, under practical conditions, at any stage of production, storage, transport, distribution or processing of food, agricultural commodities, or animal feed, bearing in mind the variations in requirements within and between regions. This takes into account the minimum quantities necessary to achieve adequate control, applied in such a manner that the amount of residue is the smallest amount practicable and which is toxicologically acceptable (WHO, 1988).

The ADI and MRLs are not permanently fixed values and as new data become available, they may be revised. In India the MRL values for pesticides are prescribed under the Prevention of Food Adulteration Act, 1954.

The Indian Council of Agricultural Research established the All India Coordinated Research Project on Pesticide Residues in the year 1984.

3. INSECTICIDE RESISTANCE

Resistance is a characteristic of populations, not of individuals. Within all populations of all species there is genetic variation. Some strains of insects may show a natural tolerance to a particular pesticide, possibly based on an ability to detoxify it by enzyme activity. If such a strain constitutes a sizeable level of the total population, it is that population which will survive a pesticide treatment and go on to multiply. A much higher proportion of its offspring will be resistant to that particular pesticide. Frequent and repeated applications can thus cause resistance to develop at an accelerated process of selection. It is likely to develop rapidly in species, which have numerous generations of offspring within a short time-span.

In 1914 Melander reported about resistance on San Jose Scale to lime sulphur. Quayle in 1916 noticed resistance of California red scale on citrus to hydrogen cyanide. Prior to 1945 thirteen insect and tick species were reported as resistant to arsenicals, selenium, hydrogen cyanide, rotenone, etc. In 1947 resistance to DDT in housefly was reported from Italy and Sweden. By 1960 resistance to organochlorines, organophosphates and carbamates was reported in about 137 species. The development of resistance may be due to genetically induced changes in species-specific behaviour of the insect, and the morphological or physiological nature of an insect species.

Behaviouristic resistance is the ability of a species to avoid doses of toxic substances, which would otherwise be lethal. For example, mosquitoes avoid surfaces treated with DDT.

Sometimes a strain of a species selected by an insecticide compound shows resistance to another insecticide compound of some other group, though the latter was never involved in the selection. This is known as 'Cross Resistance' and has been defined by Grasyson and Cochran in 1968 as 'Resistance to more than one insecticide occurs following exposure to only one compound'. For example, cross resistance has been observed mainly within the classes of the organophosphates and occasionally against DDT and some carbamates.

The most important mechanism of resistance to the organophosphate compounds is the physiological resistance, which is of a complex nature. It relates to the genetically controlled potentiation of enzymatic hydrolysis in the insect. Increase in certain hydrolases alters the relationship between oxidation and hydrolysis to the detriment of the activating oxidation but in favour of the detoxifying hydrolysis mechanisms. In the houseflies resistant to organophosphate the "aliesterases", originally present had been transformed by gene mutation into phosphates which function as degrading enzyme for organophosphates. Housefly strain resistant to malathion metabolised malaxon more rapidly. Similarly the activity of organophosphate metabolising enzymes is attributed to resistance in fenitrothion and methyl parathion. Resistance in organophosphates is exclusively associated with dominant single gene.

The principal mechanism of DDT-resistance in house-flies is the detoxication of DDT to DDE by the enzyme DDT-dehydrochlorinase.

At a global level, insect pests have developed resistance to all major classes of pesticides and will develop resistance to future pesticides as well. The situation in India is enumerated below.

(i) Insecticide Resistance in Public Health Insects: Resistance to DDT was first noticed in India in the year 1952 in the mosquito *Culex fatigans*. Mosquitoes transmitting malaria and other vector diseases were noted subsequently to become resistant to DDT and HCH in various parts of the country.

(ii) Insecticide Resistance in Household Pests: The bedbug, *Cimex lectularius*, was reported to be resistant to DDT in 1953 and subsequently to HCH and few organophosphorus compounds. Human body louse *Pediculus humanus corporis* developed resistance to HCH in 1952 and rat flea *Xenopsylla cheopis* to DDT in 1961. The housefly *Musca domestica nebula* is resistant to HCH and DDT throughout the country.

(iii) Insecticide Resistance in Veterinary Pests: So far only *Boophilus microplus* infesting cattle has shown resistance to lindane in 1963 at Mukteshwar.

(iv) Insecticide Resistance in Agricultural Pests: First instance has been resistance noticed in Singhara beetle, *Galerucella birmanica*, at Delhi to HCH and DDT in 1963. The next instance being resistance to HCH in *Spodoptera litura* in 1965 and subsequently to malathion, endosulfan and carbaryl. Similarly the diamondback moth. *Plutella xylostella*, has been reported to be resistant to DDT, parathion, fenitrothion, cypermethrin, fenvalerate, deltamethrin and quinalphos. Resistance to endosulfan and tolerance to malathion and dimethoate has been noticed in *Lipaphis eryisimi* in some areas of Punjab.

The failure to control *Helicoverpa armigera* on cotton in Andhra Pradesh during 1987-88 was traced to the development of a high degree of resistance to synthetic pyrethroids such as cypermethrin and fenvalerate in this pest species. It has been shown that the pyrethroid resistance in *Helicoverpa* is due to increased detoxification in resistant population.

(v) Insecticide Resistance in Stored Grain Pests: The flour beetle *Tribolium castaneum* was first noticed in 1971 to exhibit resistance to DDT and malathion, and subsequently to lindane and phosphine. Resistance to malathion, lindane and phosphine in the rice weevil *Sitophilus oryzae*, to malathion and lindane in the grain beetle *Oryzaephilus surinamensis*, to phosphine in khapra beetle *Dermestes granarium*, and to lindane in the Leather beetle *Dermestes maculatus* are other instances reported from India.

4. INSECTICIDE RESISTANCE MANAGEMENT (IRM)

Since 1984 the threat of insecticide and acaricide resistance development was well known. In the recent years producers, academics, government officials, advisers, distributors and growers are working together in an attempt to halt resistance development. In many instances, these groups are brought together by the industry through the Insecticide Resistance Action Committee (IRAC), a GIFAP working group founded in 1985. Resistance management forms integral part of IPM and will not succeed unless growers and distributors can be persuaded to change the ways in which they select and use agrochemical products. In India the pesticide industry as well as the agricultural universities have been suggesting various ways to contain this problem, particularly with regard to *Helicoverpa armigera*, a serious pest of cotton. A number of strategies have been employed for IRM: Judicious use of pesticides resorting to application based on monitoring the pest population in the field; use of synergist which will enhance the toxicity of a given insecticide by inhibiting the detoxification mechanism; alteration of chemicals with unrelated mode of action; a product containing two or more compounds with different modes of action; sticking closely to the recommendations on dose rates and time of application; varying sowing dates to avoid peak risk periods; use of crop varieties resistant to the pest species; use of biological control; strict crop hygiene which removes sources of infestation; and crop rotation to avoid the build-up of the pest species.

◆ Chapter 93

Pesticides and the Environment

The atmosphere is polluted by smokes, acid and sulphur dioxide vapours from factories, carbon monoxide from the exhaust gases emitted by motor vehicles, and by the pesticides. Water pollution is brought about by effluents from factories (the organic matter in such contaminated water is broken down by bacteria which consume oxygen and the oxygen demand is usually tested by 'biochemical oxygen demand' or B.O.D. test) some of which may have toxic substances like metalic zinc and copper, by crude oil mostly in seas and beaches, and by pesticides. Pollution of soil is by all agents that pollute water.

Pollution of environment by pesticides is the result of extensive and intensive cultivation necessitating continuous and more frequent use of pesticides. Pollution was not as serious a problem with the earlier phytogenous and inorganic pesticides as with the organic pesticides, some of which are highly persistent or contaminate the ground water.

Among the different kinds of pesticides organophosphorus compounds like parathion and fenthion quickly breakdown and cease to be dangerous. Birds entering a treated area a few hours after application usually survive. Damage to wild life due to methyl parathion is negligible. Systemic poisons are the least contaminants of the environment as they are degraded quickly into harmless compounds. However, the persistent chemicals such as the chlorinated hydrocarbons are mostly responsible for pollution. They are desirable with reference to the control of insects as their effects remain for a long time undesirable as regards safety to man and animals for the same reason, for a relatively long time has to be passed before consuming a treated produce to avoid possible harmful effects.

Persistent pesticides were known and in use ever since chemicals were employed in pest control. The early such pesticides were inorganic compounds containing arsenic, selenium, mercury, lead, zinc and flourine. But they were in limited use. The real pollution problem associated with the persistence of pesticides started with the use of DDT and other organochlorines. These pesticides were effective against a variety of crop pests and insect and arthropod carriers of various human and animal diseases and were cheap. Large amounts of them were produced and utilised every year. In the recent years usage of such persistent chemicals has either been withdrawn or restricted.

1. PESTICIDE RESIDUES IN SOIL

Pesticides reach soil as a result of direct application to it or by drifting during dusting and spraying to foliage or washed down by rains after application.

From soil the persistent chemicals enter into soil invertebrates or water, or are broken down by microorganisms and physical factors. Such chemicals are mostly DDT and dieldrin (aldrin also breaks down in soil to dieldrin). DDT and dieldrin are reported to be more prominent soil contaminants in western countries, perhaps because of their large scale and indiscriminate use. The persistence of chemical in soil is influenced by various factors:

(i) the granular formulations persist longer than emulsions which again persist longer than wettable powders;
(ii) heavy clayey soil retain pesticides longer than light sandy ones and both organochlorines and organophosphates persist longer in acid than in alkaline soils;
(iii) higher the organic matter and clay mineral content in a soil longer is the persistence of a chemical;
(iv) higher the temperature and soil moisture less is the persistence;
(v) the break down of insecticides is more in soils having microorganisms than in sterile soils.

The presence of persistent chemical in soil does not itself constitute a great hazard to environment except that it forms a reservoir of chemical which moves into plants grown on it and into birds feeding upon earthworms and other soil invertebrates having deposits of the chemical in their tissues. When such birds survive their flesh and eggs contain residues of such chemicals.

2. PESTICIDE RESIDUES IN WATER

Pesticides reach water in lakes, ponds, tanks, rivers and streams from application of the same in mosquito control, deposits from aerial spraying of cultivated crops, as a surface run off from soil treated with the chemical, from disposals and wash off of insecticide containers, etc. Due to the absorption of the chemicals by bottom sand mud, plankton, aquatic plants and invertebrates and of the break down due to hydrolysis, toxic concentrations in water seldom build up. However, the two main hazards of residues in water are the deposition of chemicals in the bodies of fishes, which are effective filters of suspended particulate matter and in the bodies of aquatic organisms that form the food for the fish and as a result of both of these more chemical gets deposited in the fishes than is found free in water. The accumulation of pesticides in fishes is of great significance because they form food for the man and birds.

3. PESTICIDES IN THE BIOTA

(a) In plants Plants retain pesticides on their surface or in tissues as a result of chemical control of pests. Organophosphorus compounds and systemic poisons are soon broken down but organochlorines like dieldrin, are retained for relatively long periods. It is important that crops used for human or animal food should not contain residues of pesticides and hence tolerance levels that can be permitted in crops used for food have been fixed for most chemicals.

(b) In bird Residues of organochlorines occur in the tissues and eggs of many species of birds and these residues might have accumulated from their food, mainly from fish and also from grains, leaves, etc. The birds accumulating lethal doses of the poison may get killed. This accumulation is passed on to any predatory and scavenger birds feeding upon them.

It has also been reported that residues of organochlorines in their tissues lower the vitality of chicks and eggs. However, birds lose the chemicals when they are no longer exposed to them.

(c) In Food Pollution is through application of persistent pesticides just before harvest or during storage. The important group of chemicals that tend to persist in plant tissue and are transferred to man and animals include DDT, HCH, and dieldrin in the body of animals as they get accumulated in the fat tissue and are present in milk and dairy products.

(d) In man DDT is the most common pesticide than all other organochlorines present in human tissue. It has been said that, at present, the average amount of DDT present in human body is 5 to 10 ppm. The other common residues are from aldrin and dieldrin. Organochlorines can be transferred from the mother to foetus so that babies may be born with some pesticide chemical in their bodies, and milk from such mothers will also contain the chemical that together will accumulate in the babies' bodies. However, these residues have not been proved to cause any immediate harm to man but the possible long-term effects need further studies. Fortunately in tropical country like ours the chances of breakdown of chemicals into harmless compounds are more.

The possible pollution of human and cattle food can be minimised in several ways:

1. Using less persistent chemicals like organophosphorus compounds and carbamates, which are equally or more effective than the persistent organochlorines against the pests they are usually used; however, they are more toxic to mammals than organochlorines and so adequate precautions have to be taken during and immediately after application.

2. Better use of pesticides like applying them just around plants instead of broadcasting all over the planted area, seed dressing, seedling dips, using granular formulations on or around the plants or in furrows, etc.

3. Particular microorganisms in soil degrade particular pesticides; for example a strain of the bacillus *Nocardia alba*, degrades parathion to the extent of 61% in eight days under optimum conditions. It has been found that the break-down of particular chemical is faster in soils treated with the same pesticide in the previous season because of the presence of the appropriate microorganisms in the soil. The possibility of introducing such microbical cultures to soil to hasten the break-down of pesticide will be an interesting field of exploration.

4. Resorting to control of pests through ways other than chemical, like biological method.

◆ Chapter 94

Handling of Pesticides

With the increased use of pesticides in the control of pests, greater care in handling and using these chemical compounds has become necessary since most of them are toxic to human beings and domestic animals. In largescale use of pesticides hazards may arise due to accidental or intentional poisoning, operational hazards during application, post-application hazards due to residues, etc.

Based on the mammalian toxicity, pesticides are generally classified as:

(i) non-hazardous pesticides (pyrethrum products, sulphur, etc.);

(ii) moderately hazardous pesticides (DDT, malathion, fenitrothion, carbaryl, etc.), and

(iii) dangerous pesticides (aldicarb, parathion, zinc phosphide, etc.).

1. GENERAL PRECAUTIONS

The following general precautions should be followed in handling the pesticides:

1. The pesticides should be retained in their original labelled containers.
2. The pesticides should be kept in a locked cupboard or closet so as to be out of reach of children, pets and other domestic animals.
3. Pesticides should not be stored near food stuffs or medicines.

4. The labels on the containers should be carefully read and the instructions strictly followed.
5. A separate knife should be kept for purposes of opening bags or tin containers.
6. Empty containers of pesticides should be destroyed and should not be used for any other purpose.
7. Inhaling of pesticide sprays or dusts when mixing or applying them should be avoided.
8. Dusting or spraying should never be done against the wind and when the wind is high. These operations should preferably be done in the early hours of forenoon.
9. Protective clothing and devices should be used while handling pesticides to avoid exposure to sprays or drifts.
10. Spilling of pesticides on skin or clothing should be avoided.
11. While preparing spray solutions bare hands should never be used for mixing the solution. It is advisable to use a long-handled mixer to avoid splashings.
12. While handling pesticides, smoking, eating or drinking should be avoided.
13. After application hands and other exposed parts of the body should be thoroughly washed with soap and water and new clothes should be worn.
14. The nozzles or other parts of equipments should not be blown by mouth and contaminated washers from spray appliances should be buried.
15. The appliances and empty containers should not be washed near a stream or well, as it will contaminate the water.
16. The clothes worn during spraying or dusting operations should be washed after each operation.
17. Persons engaged in handling of pesticides should be checked periodically by a physician.
18. In the case of any suspected poisoning due to pesticides the nearest physician should be called in immediately.

2. FIRST AID PRECAUTIONS

In case of pesticide poisoning call a physician immediately. Awaiting the physician's arrival, apply first aid.

1. *Swallowed poisons*: Remove poison from the patient's stomach immediately by inducing vomiting. Give common salt 15 g in a glass of warm water as an emetic and repeat until vomit fluid is clear. Gently stroking or touching the throat with the finger or the blunt end of a spoon will aid in inducing vomiting when the stomach is full of fluid. If the patient is already vomiting do not give emetic but give large amounts of warm water and then follow the specific directions suggested

2. *Inhaled Poisons*: Carry the patient (do not let him walk) to fresh air immediately. Open all doors and windows. Loosen all tight clothing. Apply artificial respiration if breathing has stopped or is irregular; avoid vigorous application of pressure to the chest. Prevent chilling. Wrap the patient in a blanket. Keep the patient as quiet as possible. If the patient is convulsing, keep him in bed in some dark room. Avoid jarring noise. Do not give alcohol in any form.

3. *Skin contamination*: Drench the skin with water. Apply a stream of water on the skin while removing clothing. Cleanse the skin thoroughly with water. Rapid washing is most important for reducing the extent of injury.

4. *Eye contamination*: Hold eyelids open. Wash the eyes gently with a stream of running water immediately. Delay of even a few seconds greatly increases the extent of injury. Continue washing until physician arrives. Do not use chemicals. They may increase the extent of injury.

5. *Prevention of collapse*: Cover the patient with a light blanket. Do not use a hot water bottle. Raise foot of bed. Apply elastic bands to arms and legs. Give strong tea or coffee. Hypodermic injection of stimulants, such as caffeine and epinephrine. Fluid administration of dextrose 5% intravenously. Blood or plasma transfusion. Do not exhaust the patient by too much or too vigorous treatment.

3. ANTIDOTES

A. General Antidotes

1. Removal of Poison: Remove poisons by inducing vomiting.
2. The "Universal Antidote": A mixture of 7 g of activated charcoal, 3.5 g of magnesium oxide and 3.5 g of tannic acid in half a glass of warm water may be used to absorb or neutralise poisons. This mixture is useful in poisoning by acids, liquid glycosides and heavy metals. Except in cases of poisoning by corrosive substances it should be followed by gastric lavage.
3. Gastric Lavage (Removal of Stomach contents): Lavage is the most important method for removing poisons from the stomach.

4. Demulcents (Substances having soothing effect): After the stomach has been emptied as completely as possible, give one of the following:

(i) Raw egg white mixed with water;

(ii) Gelatine 9 to 18 g dissolved in 570 ml of warm water;

(iii) Butter;

(iv) Cream;

(v) Milk;

(vi) Mashed potato;

(vii) Flour and Water.

B. Specific Antidotes for some Pesticides

The following emergency treatments are prescribed for poisoning by some specific pesticides.

DDT and other organochlorines: If swallowed, give 'Universal Antidote', followed by gastric lavage. Then give 28 g of magnesium sulphate (Epsom salts) in a glass of water, followed by hot tea or coffee. Inject 10 ml of 10% calcium gluconate intravenously. If necessary, inject phenobarbital 0.1 g intravenously. Feed the patient with rich carbohydrate and calcium diet to prevent liver damage.

Aldrin and Dieldrin: If skin is contaminated, wash immediately with soap and water. If swallowed, give emetic and repeat until the vomit fluid is clear. The physician may administer phenobarbital or barbiturates as for convulsion therapy. Have the patient lie down and keep quiet.

Organophosphorus compounds: If the patient has blurred vision, abdominal cramps and tightness in the chest, give two tablets of atropine (each 1/100 g). Administer artificial respiration in case of respiratory failure. Do not give morphine.

Zinc phosphide: If the patient has taken the poison within 24 hours, proceed as follows: Stir one teaspoonful of mustard powder into a glass of warm water and make the patient drink it. After vomiting has stopped, give the patient 5 g of potassium permanganate dissolved in a glass of water. After ten minutes, have the patient drink a solution made of half teaspoonful of copper sulphate in a glass of water; and fifteen minutes after treatment give the patient a solution made by dissolving one tablespoonful of magnesium sulphate

(Epsom salts) in a glass of water. If the poison has been taken earlier than 24 hours, start giving potassium permagnate solution to drink and continue with the treatment as stated alone.

Bromadiolone: Antidote is Vitamin K_1. Administered orally or intramuscularly. Repeat as necessary.

◆ Chapter 95

Plant Protection Appliances

The desired effects of a pesticide can be obtained only if it is applied in an appropriate time and in a proper method. The method of application will depend upon the properties of the pesticide, the nature of the pest or pests to be controlled and the site to which the pesticide is to be applied.

The important methods of applying pesticides are dusting and spraying. The former method has been in vogue for longer time than the latter. However, spraying is the most common method now because of certain disadvantages associated with dusting like:

(i) the loss of chemical due to drift and consequent pollution risk;

(ii) less efficient deposition of dust particles on plant surface resulting in decreased efficiency in pest control;

(iii) tendency of the chemical in dust formulation to separate itself from the carrier, if its density is widely different from that of the latter, resulting in loss of chemical; and

(iv) the increased toxic hazard to operator.

However, dusting will be an useful way of application of chemicals in areas like the vast stretches of unirrigated crop tracts with limited water supply, in hilly terrains and also in case of control of pests occurring in crops just before harvest like earhead bugs and caterpillars. There are certain disadvantages with dusting over spraying. They are requirement of less labour for the operation, coverage of a larger extent of crop per day than with spraying, and light weight of dusting appliances with less risk of corrosion.

A. DUSTING AND DUSTERS

1. General Principles

Most insecticidal dusts are made of very fine particles that may pass almost completely through a 325 mesh sieve of 44 micron aperture. Therefore, the dust particles when falling free in air either slowly settle down due to gravity or drift for long distances due to wind. The rate of deposition is directly proportional, and of drift inversely so, to the size of the particle. However, dust particles not only differ greatly in their size and shape but also many tiny particles agglomerate together during the dusting operation and hence it is very difficult to forecast the pattern of their settling and drift. The settling velocity of the particles is also influenced by the density of the dust diluent and the presence of dust conditioners such as stabilisers and fluffing agents.

It is often stated that the ability of dust particles to be deposited on plant surface is influenced by the electrostatic charge of dust particles. Leaf surfaces generally have a negative electrostatic potential. The charge on the dusts can be increased by friction or by passing the dust particle through a flow of positive ions. Such charged dusts agglomerate less, adhere to the plant surface better and distribute more evenly on both sides of leaves. However, as regards retention by the target area it is no better than the uncharged dust, as the charge is lost quickly. During spraying charged spray particles repel themselves resulting in increased swath width.

There are other significant properties of dusts that affect their storage, application, deposition and adherence. These include the bulk density, indicating the degree of fluffiness, flowability, hardness of particles causing abrasion of equipment, shape of particles, for irregularly shaped particles flow slowly, and sorption resulting in caking due to absorption or adsorption of moisture.

In general, if the amount of active ingredient of the pesticide applied per unit area is same the efficiency of pest control is unaffected irrespective of the quantity of the formulation used; for instance, 100 kg of 1% dust is as effective as 20 kg of 5% or 10 kg of 10% formulation, provided there is adequate coverage and distribution.

2. Dusters

Appliances that are used for applying dry dust formulations of pesticides are called dusters. They are either manually or power operated. All dusters consist essentially of a hopper, which usually contains an agitator, an adjustable orifice or metering mechanism and delivery tubes. A rotary fan or a bellows provides the conveying air.

(a) Manually Operated Dusters

It comprises of package dusters, plunger dusters, bellows dusters, rotary dusters and knapsack dusters, of which the last two are commonly used.

Rotary dusters : They are also called crank dusters and fan type dusters. They vary considerably in design and may be shoulder mounted, back mounted or belly mounted. Basically a rotary duster consists of a blower complete with gear box and a hopper with a capacity of about 4-5 kg of dust. The duster is operated by rotating a crank and the motion is transmitted through the gear to the blower. Generally an agitator is connected to one of the gears. An adjustable feeding mechanism is also provided. The air current produced by the blower draws the dust from the hopper and discharges out through the delivery tube, which may have one or two nozzles. Rotary hand dusters are largely used in India for dusting field crops, vegetables, small trees and bushes in orchards. The efficiency of these dusters is 1 to 1.5 ha per day.

Knapsack dusters: This consists of a dust container of 2.5 to 5 kg capacity through which air current is blown by means of bellows, which are worked by hand lever attached to one side of the container. The air blast takes the dust into delivery pipe and discharges out in an intermittent manner. Knapsack dusters are designed to be carried on the back of the operator and are more suitable for low crops and for spot applications.

(b) Power Operated Dusters In addition to the usual components like a hopper, agitator fan, discharge tubes, boom and nozzles of manually operated duster, a power operated one has a petrol engine to produce power to operate.

B. SPRAYING AND SPRAYERS

1. General Principles

The spray fluid may be a solution, an emulsion or a suspension of the toxicant. Its liquid phase is usually water or less frequently a light oil. However, water is not a good carrier for pesticide because of the hydrophilic nature of the insect cuticle, insolubility of the same and break down by hydrolysis of certain other insecticides in water and of its evaporation from small droplets thus making the particles light and hence drift. Yet water is the carrier in high volume sprays though it is minimised in low volume (LV) sprays and eliminated in ultra-low volume (ULV) sprays. To obtain an effective control of the pest, the toxicant has to be well distributed and to meet this requirement the spray fluid is broken down to fine droplets. In different types of sprays the droplets vary from 30-400 microns in size. The size also varies greatly at different distances from the point of emission from the sprayer.

The atomisation of the spray fluid is accomplished by either forcing the spray fluid under pressure, which may be hydraulic or pneumatic, through a nozzle or by emitting a jet of spray fluid into a high velocity air stream.

Insecticidal sprays are described as 'aerosols' or 'space sprays' when the spray is applied as a cloud or mist of droplets which remain suspended in space for controlling flying insects that pass through it and as 'residual sprays' when it is applied to surfaces of plants, animals or structures frequented by insects. With residual spray to control sedentary insects like scales and mealy bugs a complete coverage of plant surface is necessary but to control mobile insects a random coverage is sufficient.

Depending upon the quantity of spray fluid required per unit area, the sprays are described as high volume sprays, low volume sprays and ultra low volume sprays. With high volume spraying or full coverage spraying 400 to 1000 litres of spray fluid is required to cover a hectare of field crops. The pesticide is diluted with water. The spray droplets are large enough so that, upon emission from the sprayer, they gain momentum and reach the target. On the target surface the particles coalesce and reach the point of run off. This results in wastage of chemical. By reducing the quantity of water used in spray fluid or totally eliminating it, the cost of application can be lowered and this is accomplished in low and ultra-low volume sprays. Due to this advantage the LV and ULV sprays have gained much popularity. With LV spray the concentration of the toxicant is increased by 1-25 times with corresponding decrease in total quantity of spray fluid. Hence it is also known as concentrate spray. About 5 to 400 litres of spray fluid is used to cover a hectare of field crop and the droplet size varies from 70 to 150 microns. An intermediate range of two to four times increase in concentration of the toxicant with corresponding decrease in the volume of the total spray fluid is described as semi-concentrate or semi-low volume spray. In ULV spray the pesticide is applied undiluted, in small quantities, usually less than 5 litres/ha. The size of the droplet varies from 20 to 150 microns. In the concentrate sprays air is the carrier of the toxicant and not water as in high volume spraying. The pesticide liquid is fed into air stream flowing at high velocity. The atomisation is more with increase in air volume.

In LV sprays there is never a full coverage or full wetting of the foliage and the droplets never coalesce nor reach a point of run off. The advantages with LV sprays are:

(i) Less time and cost are involved in transport of water, and hence the cost of application is minimised;

(ii) the spraying operation is speeded up; and thus timely control of pests is possible; and

(iii) the weight of appliance is much less.

However, there is a disadvantage in that there is risk of wastage of chemical due to evaporation of water and drift of the chemical because of the smallness of droplets. To minimise this loss the LV spraying should be carried out in still air with wind velocity not exceeding 8 km/h.

2. Parts of a Typical Sprayer

A sprayer consists of definite parts, each with a definite function. The important parts are described below.

Tank: The spray fluid may be contained in a tank that is built in the sprayer as in the case of any knapsack sprayer or in a separate container as in the case of pedal pump. A built-in tank should be made of a non-corrosive metal or thick polyethylene and its capacity may range from less than one litre as in a pneumatic hand sprayer to 10 to 25 litres in a knapsack sprayer or mist blower and up to 200 litres in large sprayers. The tank should be provided with a good agitator, a strainer in the filter hole and a drain plug at the bottom to drain away the liquid after use and after cleaning.

Agitator: If the spray fluid is a solution of the toxicant it does not settle and hence does not require to be agitated. But emulsions and suspensions of wettable powders settle slowly and quickly respectively. Hence such fluids require to be agitated to prevent uneven spray strengths. Most sprayers with built-in tanks have paddle like agitators that rotate in the tank and keep the material uniformly dispersed. In the case of sprayers with no such built-in tanks the return flow of excess spray fluid from the pump helps to agitate the fluid in the separate container. But this does not evidently happen in sprayers when the outflow of liquid is equal to the inflow and in such cases frequent mechanical stirring of the fluid with a stick or rod becomes necessary.

Filters: Series of filters are provided in sprayers to strain off dirt and coarse particles from entering the nozzle and blocking the flow. Even partial block of nozzles will disturb the spray pattern and distribution. In addition to the coarse particle filter at the entrance of the tank, filters are provided in the line between the tank and the pump. Filters are also present between the pump and the boom of spray lance and also in individual nozzles.

Pump: Pumps are necessary for feeding the nozzle for delivery tubes with appropriate quantities of spray fluid for atomisation. While selecting a pump during construction of a sprayer factors like the amount of material to be delivered per minute and the pressure that must be obtained on the delivery side of the pump should be taken into consideration.

It is important to realize that in a sprayer the pump is the most vital and expensive component.

Air pumps, also known as pneumatic pumps, are used in compressed air sprayers. They force the air into the tank containing the spray fluid, which is brought under pressure. They do not pump the liquid directly.

Direct displacement pumps are of two main types, plunger and rotary. Plunger pumps are also known as piston pumps. Rotary pump consists of two closely fitted gears. Both these types of pumps displace a definite volume of liquid from inlet into the outlet.

Centrifugal pumps are fitted to high pressure booms sprayers with a capacity of 500 litres per minute.

Power source: Petrol engines coupled with the equipment or any separate engine, through power-take-off device, provides power to the power-operated sprayers.

Pressure guage: It is fixed on the discharge line. It helps to assess if other parts of the sprayer are functioning correctly and for adjusting the pressure required for the job.

Valves: The valves are important in any sprayer, because they maintain the direction of flow of the spray fluid. Ball valves, consisting of metal balls sitting perfectly on a circular seat, and spring valves, consisting of a shutter operated by spring, are the two main types used in sprayers.

Hose: Hose pipe is used for conduction of the spray fluid from the sprayer to the lance and, in the case of sprayers with no built-in tank, from the container to the sprayer. A good hose should be light, flexible, durable, non absorbent and oil-resistant. It should not impart friction to the free-flow of liquid through it, for it may result in loss of pressure, though the length and diameter of the hose may also influence such loss. Plastic and nylon hoses are much in use because they are light and cheap.

Spray Lances: They are seamless, detachable brass tubes, usually 90 cm long and have the nozzle or nozzles screwed on to their end.

Spray cut off-devices: To shut off the flow of liquid there is usually a device in the lance. It may be a stop-cock or a trigger mechanism with provision for adjusting the release of fluid either as a cone or as a jet.

Booms: Sometimes a number of nozzles can be arranged in horizontal tube called the boom or spray bar. It is normally coupled with power sprayers. Booms are usually used for treating row crops. Boom-nozzle placement combinations are available for specific jobs.

Nozzles: Nozzle is an important component in a sprayer since it breaks up the liquid issued from the machine into droplets and emit them as a spray. Depending upon the design of the sprayer and of the nozzle the size of droplets varies. Even from the same sprayer with the same nozzle the droplets may be of varying sizes forming, what is described as, a spray spectrum.

Nozzles are of different designs for different rates of discharge and for low pressure and high pressure. Hollow cone nozzles are most commonly used in crop pest and disease control. In this type of nozzle the spray fluid is made to rotate by a whirl plate, also called as swirl plate, by means of slanting holes in it or a spiral screw thread on it. The liquid passes out as a conical sheet, which soon breaks up into droplets forming a hollow cone pattern of spray. On the other hand if the whirl plate is provided with an additional hole in its centre, the fluid passing out through the latter fills up the air core in the centre of the cone and hence a solid cone pattern of spray results. Nozzles producing solid cone sprays are used where even coverage is desired as in weed control and for spot treatment.

A typical spray nozzle consists of a base, a screw cap, a disc or an orifice plate, a washer also called as spacer or seal, and the whirl plate with or without a strainer.

In low volume nozzles the spiral grooves in the whirl plate are very fine, orifice is smaller with a greatly reduced space between the body of the nozzle and the whirl plate. Such a nozzle has a built-in strainer to prevent the entry of coarse and dust particles and plugging of tiny grooves.

Nozzle tip is the most important but least expensive part of the sprayer system. The liquid sprayed takes up a hollow cone, flood, jet or flat fan pattern depending upon the type of nozzle tip used.

The nozzle may be adjustable and suitable for spraying targets, which are not within the reach of man. Adjustments may be done to give a wide angle hollow cone, to a straight solid stream. A sprayer may also carry a double swirl nozzle for spraying in two different directions simultaneously. Double nozzle is suitable for high volume application.

3. Types of Sprayers

The spraying machines may be either manually operated or by power. In either category there are sprayers working with hydraulic pressure or with air (or pneumatic) pressure. In sprayers working with hydraulic pressure, pressure is developed by the direct action on the spray fluid. This pressure forces the liquid through the nozzle. On the other hand in sprayers working with air compression system pressure is developed on the air contained in the spray tank.

(a) Manually Operated Hydraulic Sprayers

1. *Hand Syringe or Garden Syringe*: It is a single acting pump working on the principle of a bicycle pump. It consists of a cylinder or pump barrel, and a plunger or piston. Spray fluid has to be contained in a separate tank. The fluid is drawn either through the nozzle aperture itself or through a separate aperture, provided with ball valve, near the nozzle. The liquid is drawn on the return stroke of the plunger and ejected during the compression stroke. After each ejection the spray fluid has to be drawn in. The spray is made of large droplets and is just like drenching. It is useful for small scale spraying in kitchen garden and pot plants.

2. *Bucket sprayer or Stirrup-pump*: It may consist either of a double acting pump with two cylinders or a single acting pump with one cylinder. The other parts of the sprayer are the plunger assembly, foot valve assembly, hose, lance, nozzle, a stirrup and an adjustable foot rest. The plunger assembly has a plunger shaft, a handle and a travel limitation device. The pump has to be put in a bucket of any container having the spray fluid. In the single acting pump the discharge is discontinuous since the fluid is ejected only during the downward compression stroke, while in the double acting pump the discharge is continuous as the fluid is discharged during both suction and pressure strokes. However, in both cases continuous pumping is necessary. This type of sprayer is useful for spraying small areas.

3. *Knapsack sprayers*: To fit comfortably on to the back of the operator like a knapsack this type of sprayer has a flat or bean shaped tank. The tank has a capacity of 10 to 30 litres and is made of galvanised iron, brass, stainless steel or plastic. It is similar to the bucket type in principle. A lever-handle is provided for operation. It has to be continuously operated with simultaneous operation of the spray lance with the other hand. A mechanical agitator is provided inside the tank and it moves up and down inside the container due to the movements of the pump level. It is preferred for spraying rice crop; it is also used for spraying low crops, vegetables and nurseries.

4. *Rocker sprayer*: It consists of a pump assembly, a rocking-lever, pressure chamber, suction hose with a strainer, delivery hose, cut-off valve and spray lance with nozzle. By rocking movement of the lever, pressure can be built in the pressure chamber and this helps to force the liquid through the nozzle. There is no built-in tank. It can be used for spraying trees and tall field crops.

5. *Foot sprayer or Pedal-Pump*: A pedal-pump consists of a vertical pressure chamber mounted on to a stand and a plunger assembly with the plunger rod attached to a pedal in addition to the other usual components viz., a suction hose with a strainer, a delivery hose with an extension rod and spray nozzle, etc. It has no built-in tank. It works on the same

principle as the rocker sprayer except that the pedal is worked up and down by foot in this case whereas the rocker in a rocker sprayer is operated forward and backward by hand. In both cases continuous operation of pedal or rocker is required to maintain high pressure for uniform spraying. Pedal pump develops a pressure 17-21 kg and a rocker sprayer 14-18 kg/cm^3. It is easy to operate and can be used for spraying agriculture crops as well as small fruit trees. About 1 to 1.5 ha can be covered in a day.

(b) Manually Operated Pneumatic Sprayers

Since these sprayers work on a system of air compression, some air should be allowed to remain in the tank, which, therefore, should not be filled with spray fluid completely. They do not have agitators and hence are not useful for spraying materials, which settle down quickly.

Hand sprayers: The container for the spray fluid also acts as the pressure chamber. An air pump attached to the chamber projects inside. The inner end of the discharge pipe runs down to the bottom of the container and its outlet terminates in a nozzle. Attached to the pipe is a release device. The tank is filled to three-fourth and the pump is worked to force air into the space to build sufficient pressure upon the spray fluid. With the release of the release device the air pressure forces the liquid up the outlet and through the nozzle to emerge in the form of a fine continuous spray. These sprayers are used extensively in kitchen gardens, in glass houses and indoors against household insects.

Knapsack sprayers: They are adopted for spraying large quantities of liquid. They are similar to pneumatic hand sprayers in principle. A typical pneumatic knapsack sprayer comprises a tank for holding the spray liquid as well as compressed air, a vertical air pump with a handle, filling hole with a strainer spray lance with nozzle and release and shut off devices. The tank is fitted with a plastic skirt that provides a convenient rest with the back of the operator and has shoulder straps that allow it to be carried. The pump has to be worked to maintain a pressure of 2 to 4 kg/cm^2.

It is necessary that the containers in such sprayers should be made of robust material and be leak proof. Before each refilling the tank the pressure should be released slowly.

These sprayers are used in agricultural pests, and mosquito control operations.

Manually Operated Mist Blowers

The common flit gun or air atomiser is a small, handy simple appliance. It works on the principle of air blast breaking up the spray droplets and carrying them to the target. It can be of a simple compression cylinder, usually made of tin, with air pump. The pump is a flexible leather piston which, when moved up and down, allows air to pass into the compression side of the cylinder on the return stroke. Hence valves are not necessary. The outlet of the cylinder is opposed at 90° to another orifice in a tube leading out of the liquid container and thus is modified into a nozzle. The container is a simple can with a filling hole and is usually suspended beneath the outlet and of the cylinder. It may have a capacity ranging from a few millilitres to a litre. On the compression stroke the flow of air draws up the spray fluid from the tank and the opposition of the high velocity air and liquid streams results in atomisation into minute droplets of 15–50 microns. Continuous pumping is necessary though the spraying is not continuous. These appliances are useful for spot treatment in household spraying against bed bugs, mosquitoes and house flies and for treating individual plants.

Power Operated Hydraulic Sprayers

A power operated hydraulic sprayer generally consists of a petrol engine and a framework in addition to the other standard components of a sprayer; various types of booms with equidistantly fixed nozzles may be attached with these sprayers. These include the stretcher sprayers, wheel-barrow sprayers and traction sprayers.

Power Operated Pneumatic Sprayers

In this sprayer compressed air from a compressor, which is driven by a small engine, is forced into the liquid container. The capacity of the container is about 45 litres. An outlet from the container may bear lances or guns or a small boom with nozzles. Sprayers of this type with much larger tanks of 250 – 2000 litres capacity and more powerful compressors are mounted on a tractor. Such large size sprayers are useful for spraying over extensive areas of crops in the plains.

Low Volume Sprayers

In these sprayers the spray fluid is atomised with the help of an air stream at high velocity. The knapsack mist blower now much in use in India delivers 6.8 to 42.5 m^3 of air/min at a velocity of 200 to 420 kmph. The tank is made of thick polyethylene and has a capacity of 10 to 12 litres. The fuel tank capacity is 10 to 15 litres. The blower is light, 12-20 kg inclusive of accessories and is provided with 1.2 to 3.0 hp petrol engine. This sprayer fitted with suitable accessories can also be used for dusting; during dusting the air blast enters into the tank through a tube with several holes.

ULV Applicators

The pesticide, in ULV formulation, is used undiluted at a quantity less than 6 l/ha and usually at 0.5 to 2.0 l/ha for field crops. The droplet size varies from 30 – 150 microns. Such small droplets cannot be forcibly propelled over a distance and their distribution, therefore, depends on gravity and air movement.

With ULV application the job can be done quickly and in time. Also on the basis of active ingredient ULV formulations are cheaper than EC formulations; spray deposits from ULV formulations persist longer than that from emulsions. However, the major disadvantage with ULV application is the availability of special ULV formulations of pesticides; the qualities for such a formulation are low volatility, low phytotoxicity and high concentration.

The ULV application is made by mist blowers fitted with restrictor nozzle or air craft with special nozzles. With ground spraying equipment for ULV, spraying an area of 8 ha can be covered in a day against 3 ha in LV spray with power operated knapsack and 0.5 to 0.8 ha in high volume with manually operated sprayers.

◆ Chapter 96

Aircraft Application of Insecticides

THE FIRST practical use of an aircraft in insect control work was carried out in Ohio, USA, in 1921 when lead arsenate was dusted to control the sphinx *Ceratoma catalapae*. In India this method has been used in pest control since 1951. The Ministry of Food and Agriculture of the Government of India set up an aerial service. The Directorate of Plant Protection at New Delhi and private agencies cooperated by extending their service. In India aerial spray applications of concentrated chemicals at ultra low volume rates and without being diluted with water was employed in the control of mosquitoes and pests of paddy, wheat, sugarcane and cotton (Fig. 95.1). At present, aircraft application of insecticides is limited in India.

Aircraft application of insecticides have certain advantages. A large area could be speedily covered (200 to 800 hectares) in the application of spray or dust. If ultra low volume application is carried out the area covered by a plane will be twice or even three times more than that covered under ordinary methods. Accessibility is another advantage. Forest plantations, extensive crop fields etc. can be treated. Aerial spraying has an advantage over dusting because of the drift and possibilities of ready adjustment of dosage, rate and droplet size. However, dusting with fixed wing aircraft does not achieve coverage of lower leaf surfaces. Bad weather, mechanical troubles, etc. may delay the programme. While aircraft application has an advantage in that there is saving in manpower and machinery, it should also be mentioned that risks and accidents could not be ruled out.

▲ **Fig. 96.1** *Spraying insecticide on rice crop with helicopter*

There are obvious advantages in using a helicopter. It is easy to manoeuvre than a fixed wing aircraft. Navigational hazards like trees, wires, etc. do not form serious impediments: there is minimal drift of the pesticide; the pilots have better vision of the field of application; specialised landing or take off are not necessary; ferrying is quicker and the low altitude flight is helpful.