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MODULE 1

UNIT 1 INTRODUCTION TO THE SYSTEMATICS OF INSECTS AND MITES

CONTENTS

1.0 INTRODUCTION

In this unit you would be studying about the evolution of systematics especially with respect to insects, the elements and objectives of classification and the general classification of insects and mites.

2.0 OBJECTIVES

At the end of the unit, you should be able to:

- define and explain systematics
- discuss the objectives of classification
- state the elements of classification
- give an outline of the general classification of insects and mites

3.0 MAIN CONTENT

3.1 Introduction to Systematics

The naming and ordering of objects into groups is probably the most fundamental step in the development of scientific principles. For instance, in chemistry the discovery and naming of elements and organizing them into the periodic table became the basis for the development of the science. .

In biology, the naming of organisms is referred to as **nomenclature,** and ordering them into a hierarchy of categories is known as **classification.** A related science, taxonomy, involves the theoretical basis for classification and the study of classification schemes. Specialists working in these areas usually are referred to as **Systematists;** their overall activity, **systematics,** is the study of the diversity and classification of organisms.

Because of the tremendous size of the class Insecta, the naming and classification of all insects would seem to be a difficult, if not impossible achievement. However, hundreds of insect systematists around the world work daily on this task, and great strides have been made in understanding insect diversity. Indeed, some experts estimate that nearly 7,000 species new to science are discovered, named, and classified each year! However, there is still much systematics work to be done before insects will be as well known as birds, mammals, and other animals.

The study of the classification or taxonomy of any insect is called systematic entomology. If one works with a more specific order or even a family, the term may also be made specific to that order or family, for example systematic dipterology.

3.2 Objectives of Classification

Like the periodic table of chemistry, classification allows us to order what we know about insects and to compare and contrast characteristics. From these comparisons, we formulate predictions about relationships, including those with both evolutionary and ecological meaning. For instance, members of the same **species** are expected to behave similarly in their food habits, tolerances to environmental extremes, developmental patterns, and other ways. A group of similar species, put together in a higher category called a **genus,** also could be predicted to share somewhat similar ecologies and to have evolved from the same ancestor. Moving to higher and higher groupings in classification, we expect more and more diversity within the grouping.

A major application of classifications is in identification of insect specimens. Identifications of major groups such as insect orders can usually be made at a glance; however, finer identifications often require the use of **keys.** Most keys comprise a sequence of paired statements and questions that allow the user to eliminate alternative options and eventually associate the unknown specimen with a name. Many keys exist for orders and families of insects. Some of the most useful are those written by D. J. Borrer, C. A. Triplehorn, and N. F. Johnson *(An Introduction to the Study of Insects)* for the insects of North America, and by C. T. Brues, A. L. Melander, and F. M. Carpenter *(Classification of Insects)* for the insects of the world.

Correct identification is the first step and probably the most important one in dealing with a Pest. It allows us to retrieve the information required for insect pest management. Without identification, we have no basis for predicting injury and advising action.

3.3 Elements of Classification

The classification of organisms is based on a hierarchy of categories, with the most inclusive occurring at the top and the least inclusive at the bottom. The major categories used in animal classification are **phylum, class, order, family, genus, and species.** But for added distinction in large, diverse groups, many other categories fall between these major ones. For example, a subclass category is commonly present below the class category and a **superfamily** category above the family category.

An example of the major categories for the European corn borer shows the following classification:

Phylum-Arthropoda
Class-Insecta
Order-Lepidoptera
Family-Pyralidae
Genus-*Ostrinia*
Species-*Ostrinia nubilalis*

Note that each category consists of only one word except the species category. The scientific name of a species is **binomial;** it is composed of two names, a genus name and a specific name, also called a **specific epithet.** Unlike all the higher categories, the specific name cannot stand alone; it must be used with the genus name. In zoology, it is conventional, but not required, for the species name to have the name of the person who first described the species as a suffix. Therefore, we might see the species name written as *Ostrinia nubilalis* (Hubner). The parentheses around the author name indicates that when Hubner originally described the species, he placed it in another genus. An author name without parentheses means that the species remains in the genus originally used by the describing author. Author names; are used often in technical systematic literature; they are omitted in this book.

The system of binomial nomenclature we use today for classification was advanced by Swedish naturalist Carolus Linnaeus, who first used it consistently in 1758. Strict rules and conventions apply few name assignment, and these are stated for zoology in the *International Code of Zoological Nomenclature.* Although they may be based in any language, scientific names are Latinized and usually refer to some characteristic of the animal or group named. The binomial of a species is always printed in italics or, if handwritten, is underlined to indicate italics. The names of genera and higher categories begin with a capital letter, but the specific name of the species and subspecific names always begin with a lowercase letter, as in the subspecies *Diabrotica undecimpunctata undecimpunctata Mannerheim*. In this example, the third name indicates a subspecies, a group of individuals of the same species that have differences in body form or color and geographical distribution. .

A frequently used name for the species, the common name, is not covered by the formal rules of nomenclature. The name "European com borer" is a common name, somewhat similar to a nickname. Such names are often used in insect pest management because they are easily pronounced compared with the Latin name. However, because no formal rules govern these names, we may find different names or versions used in different localities for the same species, and confusion may arise. Because there is only one scientific name, it is always the safest name to use to avoid problems of semantics. In the United States, a list of common names approved by the Entomological Society of America is presented in Common Names of Insects and Related Organisms. These names are merely recommended and are not necessarily followed by the international scientific community.

The species category plays the central role in systems of classification. It is the only category that is real; in other words, it is the only natural group. The species is a complex unit that is sometimes difficult to define, but a widely used definition applied to the species concept is as follows: a group of interbreeding individuals that are similar in body structure and that produce fertile offspring; moreover, these groups are reproductively isolated from other such groups. This is the biological species definition.

All other categories of the hierarchy are based on the species category but are abstractions. Even though they are derived from suspected pathways of insect evolution, these other categories are human contrivances used for convenience. Because this is so, we find many differences of opinion as to where to "lump" and where to "split" categories; therefore, many different schemes of insect classification result.

3.4 General Classification of Insects

Insects are the most successful group of animals. They are a large and varied group. Of the 1 million or so known species of animals, over 850,000 or 76% are insects. Thousands of species remain to be discovered.

Insects live in almost every type of environment; land, sea and fresh water. The distribution of insects extend from the poles to the tropics. The extensive distribution of insects is probably as a result of;

a) Their ability to fly
b) Their small size
c) The production of resistant eggs that can be carried by air, water currents, animals, etc
d) Their resistance to desiccation
e) Their adaptability

In general, this list proceeds from the most primitive insects to the most highly evolved.

Kingdom: Animalia
Phylum: Arthropoda
Class: Insecta

Subclass: Apterygota – primitively winged insects
Order: Protura - proturans
Order: Collembola - springtails
Order: Diplura – two-pronged bristletails
Order: Thysanura – silverfish (the three pronged bristletails)
Order: Microcoryphia – jumping bristletails

Subclass: Pterygota – winged and secondarily wingless insects

Superorder: Exopterygota – simple body change during growth
Order: Ephemeroptera - mayflies
Order: Odonata – dragonflies and damselflies
*Order: Orthoptera – grasshoppers, crickets

Family: *Acrididae – grasshoppers / locusts*

Family: *Tettigoniidae - longhorn grasshoppers and katydids*

Family: *Gryllidae – crickets*

Order: Dermaptera - earwigs

*Order: Isoptera - termites

Family: *Kalotermitidae – drywood termites*

Family: *Rhinotermitidae – subterranean termites*

Order: Embioptera - web spinners

Order: Plecoptera - stoneflies

Order: Zoraptera

Order: Psocoptera - bark and book lice

*Order: Mallophaga - biting lice

*Order: Thysanoptera - thrips

*Order: Hemiptera – bugs

Suborder: ***Heteroptera – true bugs***

Family: *Pentatomidae – stink bugs*

Family: *Family Coreidae – leaffooted bugs*

Family: *Lydaeidae – seed bugs*

Family: *Nabidae – damsel bugs*

Family: *Anthocoridae – minute pirate bugs*

Family: *Miridae – plant bugs*

Suborder: ***Homoptera – aphids, scale insects, cicadas, whiteflies, psyllids and hoppers***

Family: *Cicadidae – cicadas*

Family: *Cicadellidae – leafhoppers*

Family: *Psyllidae – jumping plantlice*

Family: *Aleyrodidae – whiteflies*

Family: *Aphididae – aphids*

Order: Dictyoptera - cockroaches and mantids

*Order: Siphunculata / Anoplura - sucking lice

Family: *Pediculidae – head and body lice*

Family: *Pthiridae – crab lice*

Order: Grylloblatodea

Order: Phasmida - stick-insects

Superorder: Endopterygota – complex body change during growth

*Order: Neuroptera – lace-wings, antlion flies, alderflies, snakeflies fishflies, owlflies

*Order: Coleoptera – beetles, weevils, fireflies

Family: Carabidae – ground beetle

Family: Staphylinidae – rove beetles

Family: Scarabaeidae – scrab beetle

Family: Buprestidae – metallic wood borers

Family: Elateridae – click beetles

Family: Dermestidae – dermestids

Family: Coccinellidae – ladybird beetles

Family: Meloidae – blister beetles

Family: Cerambycidae – longhorned beetles

Family: Chrysomelidae – leaf beetles

Family: Curculionidae – weevils

Family: Scolytidae – bark beetles

Order: Strepsiptera – twisted-winged parasites, stylops

Order: Mecoptera – scorpion flies

Order: Trichoptera - caddis flies

*Order: Lepidoptera - butterflies and moths

Family: Tineidae – clothes moths and others

Family: Psychidae – bagworm moths

Family: Tortricidae – totricid moths

Family: Pyralidae – snout and grass moths

Family: Papilionidae – swallowtail butterflies

Family: Nymphalidae – brushfooted butterflies

Family: Lasiocampidae – tent caterpillars and lappet moths

Family: Sphingidae – sphinx moths

Family: Noctuidae – noctuid moths

*Order: Diptera – true flies (houseflies, mosquitoes, midges, sandflies)

Family: Culicidae – mosquitoes

Family: Cecidomyiidae – gall midges

Family: Tabanidae – horse flies and deer flies

Family: *Syrphidae – flower flies*
Family: *Tephritidae – fruit flies*
Family: *Muscidae – muscid flies*
Family: *Tachnidae – tachinid flies*
*Order: Siphonaptera - fleas
*Order: Hymenoptera – ants, bees, sawflies and wasps
Family: *Tenthredinidae – tenthredinid sawflies*
Family: *Cephidae – stem sawflies*
Family: *Braconidae – braconids*
Family: *Ichneumonidae – ichneumons*
Family: *Trichogrammatidae – minute egg parasites*
Family: *Formicidae – ants*
Family: *Vespidae – vespid wasps*
Family: *Apidae – bumble bees, honey bees*

Note: the orders marked * are major economically important insects

3.5 General Classification of Mites

Mites comprise the Acari, which are the largest group within the arthropod class Arachnida, with over 48,000 described species. This number is misleading because it is estimated that only between 5% and 10% of all mite species have been formally described. In contrast with other arachnid groups such as spiders and scorpions, mites are distinctive in both their small size (adult body length ranging from 0.1 to 30 mm) and their ecological diversity. Some mites are predators, like almost all other arachnids, but mites may also feed on plants, fungi, or microorganisms or as parasites on or in the bodies of other animals. Mites are among the oldest known groups of arthropods, with a fossil record beginning in the Devonian period.
A general classification of mites is as follows:

Kingdom: Animalia
Phylum: Arthropoda
Class: Arachnida
Order: Acari / Acarina

Suborder: *Mesostigmata – parasitic mites*

Suborder: *Prostigmata – spider mites*

Suborder: *Astigmata – itch and scab mites*

4.0 CONCLUSION

As you studied this unit, the background of systematics, the objectives and elements of classification as well as a general classification insects and mites were highlighted and explained.

5.0 SUMMARY

In this unit, you have studied the evolution of systematics. The main objectives of classification include the identification of organisms. The elements of classification in which they major categories are: kingdom, phylum, class, order, family, genus and species. Insects and mites are classified on the basis of features peculiar to each division.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1a. Explain animal systematics especially in relation to insects

1b. Discuss the naming and ordering of organisms in biology

2a. State the main elements of classification

2b. What do you understand by the binomial system of nomenclature of a species

3. What are the objectives of classification?

4a. State the factors responsible for the success / extensive distribution of insects

4b. In outline form, give a general classification of insects with examples (including local ones)

5. Write on the classification of mites with examples

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http://insect-world.com/main order.html
Contains descriptions and discussions of insect orders

http://www.insects.org/
Colourful photos of major insects orders and a key for identifying orders. Gives links to other entomology sites

UNIT 2 BIOLOGY OF MAJOR ECONOMICALLY IMPORTANT INSECTS

CONTENTS

1.0 INTRODUCTION

Insects are extremely numerous and have been termed the most successful animal species in terms of numbers. In this unit, you would be studying the various economic classes of insects with subgroups and examples in each category, the biology of a major economically important insect, the honey bee. It is a beneficial insect as the honey derived from it is consumed by man and used for other purposes such as in medicine. The biology and life cyle of the bee will also be treated in this unit.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- Give an economic classification of insects with examples in each category
- Differentiate between the various economic classes of insects
- State the general characteristics of insects
- Describe the biology and lifecycle of a honey bee

3.0 MAIN CONTENT

3.1 Economic Classification of Insects

Insects are a very important group of animals because of their beneficial and adverse effects on the life of man. They have made a tremendous impact on the environment, on human activities and health. Medical, economic and agricultural Entomology are important branches of science.

Insects can be classified as follows based on their economic importance.

3.1.1 Injurious Insects

a) *Pests of cultivated plants (crop pests)* : Each cultivated plant harbours many insect pests which feed on them and reduce the yield of the crop. Field and horticultural crops are attacked by many insect species. (e.g.) cotton bollworm, Rice stem bores.

b) *Storage pests* : insects feed on stored products and cause economic loss. (e.g.) Rice weevil, Pulse beetle.

c) *Pest attacking cattle and domestic animals* : Cattle are affected by pests like Horse fly, Fleshfly, Fleas and Lice. They suck blood and sometimes eat the flesh.

3.1.2 Beneficial Insects

a) Productive insects

i) ***Silk worm*:-** The silk worm filament secreted from the salivary gland of the larva helps us in producing silk.

ii) ***Honey bee*:-** Provides us with honey and many other by-products like bees wax and royal jelly.

iii) ***Lac insects***:- The secretion from the body of these scale insects is called lac. Useful in making vanishes and polishes.

b) Insects useful as drugs, food, ornaments etc,

i) ***As medicine*** e.g. Sting of honey bees- remedy for rheumatism and arthritis, Eanthoridin extracted from blister beetle –useful as hair tonic.

ii) ***As food*** - for animals and human being.

For animals - aquatic insects used as fish food.

Grass hoppers, termites, pupa of moths. They have been used as food by human beings in different parts of the world.

(c) Ornaments, entertainers

- Artists and designers copy colour of butterflies.
- Beetles worn as necklace.
- Insect collection is an hobby

(d) Scientific research

Drosophila and mosquitoes are useful in genetic and toxicological studies respectively.

3.1.3 Helpful Insects

(i) ***Parasites*:** These are small insects which feed and live on harmful insects by completing their life cycle in a host and kill the host insect. E.g. egg, larval and pupal parasitoids

(ii) ***Predators*:** These are large insects which capture and devour harmful insects. E.g. Coccimellids, Preying matritids.

(iii) ***Pollinators*****:** Many cross-pollinated plants depend on insects for pollination and fruit set. E.g. Honey bees, aid in pollination of sunflower crop.

(iv) ***Weed killers*****:** Insects which feed on weeds and kill them. E.g. Parthenium beetle eats on parthenium. Cochneal insect feeds in *Opuntia dillenii*.

(v) ***Soil builders*****:** soil insects such as ants, beetles, larva of cutworms, crickets, collembola, make tunnels in soil and facilitate aeration in the soil. They become good manure after death and enrich soil.

(vi) ***Scavengers*****:** Insects which feed on dead and decaying matter are called scavengers. They are important for maintaining hygiene in the surroundings. E.g. Carrion beetles, Rove beetles feed on dead animals and plants.

3.1.4 Household and Disease Carrying Insects

i) *Pests which cause damage to belongings of human beings* like furniture, wool, paper etc. E.g. Cockroaches, furniture beetle, sliver fish, etc.

ii) *Pests which cause painful bite, inject venoms*. E.g. Wasps, bees sting us. Hairy caterpillar nettling hairs are poisonous. Mosquitoes, bugs bite and suck blood from us.

iii) *Disease-causing*: Mosquito - Malaria, Filariasis, Dengue fever. Housefly- Typhoid, Cholera, Leprosy, Anthrax

3.2 Biology of A Major Economically Important Insects

Characteristics of Insects

i. Insects like other mandibulates have one pair of pre-oral antenniform appendages

ii. The insect body is usually divided into three parts – head, thorax and abdomen

iii. The insect head consists of six segments bearing a pair of antennae (segment 2), a pair of mandibles (segments 4), 1st maxillae (segment 5) and a pair of 2nd maxillae (segment 6). Compound eyes are present

iv. The thorax consists of three segments and bears three pairs of walking legs ventrally and two pairs of wings dorsally

v. The abdomen consists of eleven segments usually and bears no ambulatory appendages

vi. Insects respire by means of trachea which open via segmentally arranged spiracles

vii. Excretion in insects is by means of malpighian tubules

3.2.1 Biology of a Honey Bee (*Apis*)

There are an estimated 30,000 bee species worldwide. The vast majority of these species are solitary and do not produce honey or large nests with young, and therefore do not exhibit colony defense.

When one typically thinks of a bee, the species that typically comes to mind is the western honeybee, *Apis mellifera*. The genus *Apis* is comprised of eight species. *Apis mellifera* is comprised of 24 different races. The most common commercial production race is *Apis mellifera ligustica*, commonly referred to as Italians. This race is known for its high rate of honey production and its gentle nature, making it a favorite in apiaries, commercial bee production facilities.

The majority of bees that one sees outside of a hive are workers (sterile females). A typical honeybee colony consists of 50,000-60,000 sterile workers, 500 to 1000 drones (fertile males) and one queen, the only fertile female in the colony and mother of the entire population of the hive.

Some people confuse bees with wasps. Bees tend to be vegetarians and are generally hairy, whereas wasps tend to be carnivorous and hairless.

3.2.2 Life cycle of a Honey Bee (*Apis*)

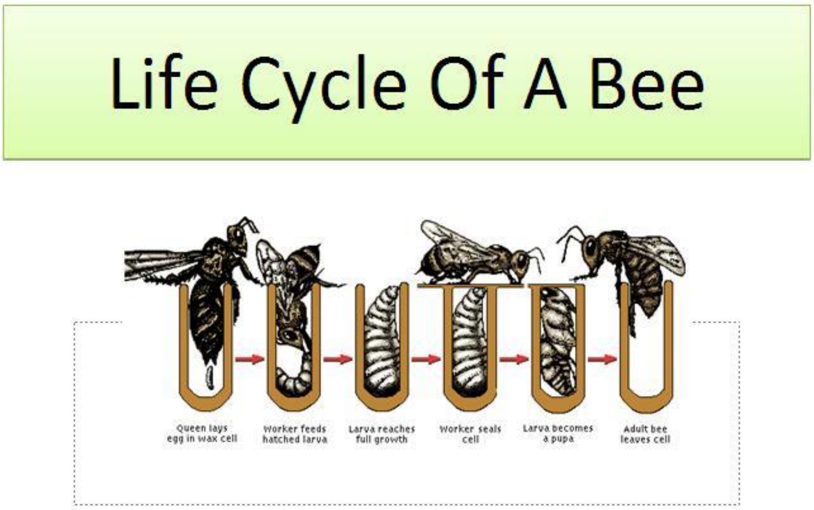

Fig. 2.1: Life cycle of a bee

Typical of the most advanced insects, bees exhibit **complete development or complete metamorphosis**. This means that the young and the adults look very different and the diet of the young and the adults typically differ, preventing the parents from competing with their offspring for resources. The life stages are egg, larva, pupa and adult. Development from egg to new worker typically takes two to three weeks.

Egg

The eggs are described as having an appearance similar to sausage-shaped poppy seeds. Each egg has a small opening at the broad end of the egg, the micropyle, that allows for passage of sperm. Hatching takes place three days after egg laying.

Larva

The larval stage lasts eight to nine days. Upon hatching, the larva is almost microscopic, resembling a small, white, curved, segmented worm lacking legs and eyes. For the first two days, all larvae are fed a diet of royal jelly. Beginning the third day, worker larvae are fed honey, pollen and water, while the larvae destined to become queens continue to receive royal jelly throughout their larval lives. Regardless of whether the larva is male or female, it molts five times during its larval stage.

Care of the larvae is constant. Each larva receives an estimated 10,000 meals during this stage. Larval weight increases 5½ times during the first day, 1,500 times in six days.

Larval stage durations vary:
- 5.5 days for queens (fertile females),
- 6 days for workers (sterile females), and
- 6.5 days for drones (fertile males)

Pupa

The pupal stage is a stage of massive reorganization of tissues. Organs undergo a complete reorganization, while body changes from the wormlike larval body shape to the adult body shape with three distinct body regions. Pupation periods vary: queens require up to 7.5 days, drones require14.5 days, while workers require 12 days.

Adult

Adult bees are either workers (sterile females), queens (fertile females), or drones (fertile males). A typical honeybee colony consists of 50,000-60,000 sterile workers, 500 to 1000 drones (fertile males) and one queen, the only fertile female in the colony and mother of the entire population of the hive.

Workers: provide virtually all of the efforts required to maintain function within a hive. During the latter part of their life, each will travel up to two miles in search of pollen, nectar and water. Each worker typically goes on ten food gathering journeys per day, each lasting approximately one hour. This heavy workload takes its toll; each worker lives for about a month prior to wearing out.

Immediately after emerging from its pupal cocoon within one of the many brood cells, it immediately goes to work. During the first four days of its adult life, each worker is cleaned and fed by the other bees while its body hardens and it begins to produce substances in various glands. Activities during the next seventeen days include cleaning, feeding larvae, manipulating wax, processing honey, guard duty and air conditioning the hive by fanning. Any of these activities can be done at any time based on the needs of the colony.

On day 21 the worker leaves the hive, and works for another 20 days, bringing in pollen, nectar and water before taking its final flight away from the hive and dying.
Pollen, a plant protein source for the young, provides nitrogen, phosphorus, amino acids, and vitamins essential for development of these vegetarians. Pollen is collected in pollen baskets (corbicula) on the workers' rear legs.

Nectar, obtained from floral nectaries deep within flowers, provides a pure carbohydrate source for all stages. Each workers fills her honey sac within her digestive system, increasing her weight by up to one half. Upon arrival at the hive, the worker regurgitates the contents of the honey sac to the younger workers within the hive. These younger workers receive the nectar, which is processed by enzymes within their honey sacs, and tipped into storage cells where it ripens for five days. At this point the substance becomes honey, and the cell containing it is capped for storage. Nectar from 5 million flowers is required to produce a single pint of honey.
Water, the final substance brought to the hive, is essential for hydrating all of the individuals within a hive and cooling it throughout the year. Approximately five gallons are required to hydrate and cool the colony each year.

Queens: can be distinguished from workers by their longer tapered abdomens and greater size. Queens have the longest lifespan of all of the bees within the hive. Their major role centers around egg laying to insure the vast numbers of individuals required to maintain a hive.

Colonies will make a new queen if the original is ailing or infertile. This is done by producing a special wax cell around 7 or 8 fertilized eggs, the oblong armored incubator looks somewhat like a peanut. Eggs and larvae are slathered with royal jelly (vitamin-rich hormonal goo made by workers) for a two-week period, after which a new queen emerges. The first new queen to emerge stings all her sisters within the specialized wax cell (all of whom are potential queens) and may kill the original queen (her mother).

Five to fifteen days after emergence from her pupal cocoon and cell, the young queen flies off, mating with as many as ten drones over a several day period. She will store the sperm from these matings in a spermatheca for the duration of her life, never to mate again.

She returns to the hive and begins laying up to 1,500 eggs per day. Queens typically lay 200,000 eggs over their lifetime. After two to four years, the queen uses up all of her stored sperm and begins producing unfertilized eggs, which give rise to drones. Usually the workers raise one or more queens from the last of the fertilized eggs to replace the new queen. To maximize hive productivity, honey farmers replace the queen annually or every other year.

Drones: are the male bees within a colony. Drones can be distinguished from workers and queens by their large size, rectangular abdomens, large conspicuous eyes, and noisy flight. All drones lack a sting, and have more eye facets than a worker (6,000-7,000 vs. 3,000-5,000).

Drones result from unfertilized eggs. They emerge 24 days after the egg is laid. Drones are capable of extracting honey four days after emergence, but prefer to be fed by workers. Unlike workers (sterile females), drones can't fly well, don't gather food for the colony, don't clean, don't secrete wax, and do not care for young. The role of the drones is largely to fertilize new queens. A group of drones follows each virgin queen on her early flights. Several males will mate with each virgin queen while flying, dying immediately after mating since his reproductive organs and the end of his abdomen break off, temporarily plugging the end of the queen's reproductive tract and abdomen.

Assuming all goes well, drones typically live for about 50 days. If there is a fertile female in residence, the workers may withhold food from the drones or gnaw off the drones' wings and legs. By fall, all of the males and male larvae are evicted from each colony.

4.0 CONCLUSION

The importance of insects cannot be over-emphasized and the knowledge of their biology and life cycle is useful in order to be able to harness the maximum benefits from them in the case of beneficial insects and utilize the knowledge to be able to control or eliminate them in the case of insect pests and parasites.

5.0 SUMMARY

Insects can be classified based on their economic importance. We have injurious insects such as crop pests (e.g. cotton bollworm), storage pests (e.g. rice weevil), etc., beneficial insects such as productive insects (e.g. honey bee from which honey and other by-products are obtained), insects useful as food, drugs (e.g. sting of honey bees is a remedy for rheumatism and arthritis), insects useful in scientific research (e.g. *Drosophila*), etc., helpful insects such as pollinators (e.g. honey bees), scavengers (e.g. carrion beetles), etc. and household / disease-carrying insects such as Mosquito, Housefly, Wasps, etc.

The honey bee is an example of a major economically important insect due to its benefits as mentioned above. Hence, knowledge of its biology and life cycle is therefore important in order to harness the maximum benefits from it. Bees exhibit complete development or complete metamorphosis and the life stages are egg, larva, pupa and adult.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. Give a succinct economic classification of insects

2. Describe the economic classes of the following insects
   a. Honey bee
   b. Silk worm
   c. Rice weevil
   d. Cotton bollworm
   e. Mosquito

3. State the characteristics of insects that you know

4. Explain the biology of the honey bee

5. Bees are said to exhibit complete metamorphosis or development, explain

6. Discuss with diagram the life cycle of a honey bee that you know

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UNIT 3 BIOLOGY OF MAJOR ECONOMICALLY IMPORTANT MITES

CONTENTS

1.0 INTRODUCTION

Mites are a very important and highly specialized group of Arachnids. They are more numerous than ticks. Mites often occur in fantastic numbers, especially in soil and litter where they are important in litter decomposition especially in dry areas.

Although mites are not insects, entomologists are often called upon to deal with them because of their agricultural importance. Mites are economically important in that some species attack food, e.g. cheese mite, flour mite. Some attack living plants. Other attack man, e.g. scabies is caused by the hair follicle mite, *Sarcoptes scabei.*

Many free living mites are predaceous carnivores while others are omnivorous scavengers. The great diversity of feeding habits among mites is related to the miniaturization that characterizes the group.

2.0 OBJECTIVES

At the end of this unit, you should be able to;

- Describe the body structure of a mite
- Discuss the biology of the itch mite in terms of its morphology and life cycle
- Draw the life cycle of the itch mite showing the various developmental stages

3.0 MAIN CONTENT

3.1 Body Structure of Mites

Unlike insects, with bodies divided into head, thorax, and abdomen, the arachnid body is ancestrally divided into two functional units, the prosoma (the first six body segments) and the opisthosoma (the remaining segments). The body of a mite is further modified in that these original units are fused. A secondary subdivision separates the first two body segments into a structure termed the gnathosoma, specialized for feeding, and the remainder of the body, termed the idiosoma, containing organs of locomotion, digestion, and reproduction. Most mites show no evidence of external body segmentation, other than the serial appendages. The gnathosoma bears the first two pairs of appendages, the chelicerae, which may retain the ancestral chelate, or pincer-like form, or may be highly modified as stylets for piercing and sucking; the pedipalps, which may be almost leglike, are strongly modified for grasping prey or attaching to a host or highly reduced. The anterior idiosoma typically bears four pairs of walking legs, the first pair of which may be modified as antenna-like, sensory structures. Legs may also be modified for attaching to a host. Occasionally legs of males are modified for grasping a female during mating or for intraspecific combat. The mite's body cuticle may be entirely soft, divided into a number of hard, sclerotized plates, or almost entirely sclerotized. In a few mites, crystalline, mineral salts also strengthen the cuticle. Such modifications balance the needs for flexibility in movement and protection from predators. The body surface bears setae, typically hair-like sensory organs, arranged in characteristic patterns in different subgroups of mites. Setae are primarily hair-like, but may take on an incredible variety of shapes, from thick spines, to flat plates, to highly branched, feather-like forms. The pedipalps and legs also bear tactile setae as well as chemosensory structures termed solenidia, which are organs of smell and taste, and other specialized sensilla that are sensitive to infrared radiation. Simple eyes, or ocelli, may be present on the anterior idiosoma, and specialized sensory organs, the trichobothria, on the anterior idiosoma or legs may detect vibrations or electric fields. Like other arthropods, the inside of a mite's body is a hollow cavity, the hemocoel, in which the internal organs are surrounded by fluid, the hemolymph. Hemolymph distributes food materials and waste products and contains hemocytes, which are the cells that serve as the mite's immune system, but it does not contain oxygen-binding proteins as are found in the blood of vertebrates and some other arthropods. The mite's digestive system is divided into the three parts typical of arthropods: foregut, midgut, and hindgut. The midgut may be divided into diverticulae for food storage, particularly in parasitic mites. Some mites lack a connection between the midgut and the hindgut; these mites feed only on fluids and do not defecate. The hindgut in these mites is transformed into an excretory organ for elimination of nitrogenous wastes. Other mites, with entire guts, may have Malpighian tubules, like insects, extending from the junction of the midgut and hindgut as excretory organs. The internal reproductive system typically consists of a single ovary (paired in the Astigmata) in the female and paired testes in the male. Females typically possess a spermatheca for sperm storage after insemination, and both sexes have various accessory glands and ducts to the exterior as part of the system. Tracheal systems for respiration have evolved independently a number of times in the Acari. These open at spiracles, or stigmata, on various parts of the body in different groups. Other mites lack any respiratory system, and gas exchange occurs through the cuticle in these groups.

3.2 Biology of the Itch Mite (*Sarcoptes scabiei*)

Sarcoptes scabiei or the itch mite is a parasitic arthropod that burrows into skin and causes scabies. Animals affected include not only human but also wild and domesticated dogs and cats in which it is one cause of mange. Also affected in the wild are ungulates, boars, bovids, wombats, koalas, and great apes.

3.2.1 Morphology

Adult scabies mites are spherical, eyeless mites with four pairs of legs. They are recognizable by their oval, ventrally flattened and dorsally convex tortoise-like body and multiple cuticular spines. Females are 0.3–0.45 millimetre (0.012–0.018 in) long and 0.25–0.35 millimetre (0.0098–0.014 in) wide, and males are just over half that size.

3.2.2 Lifecycle

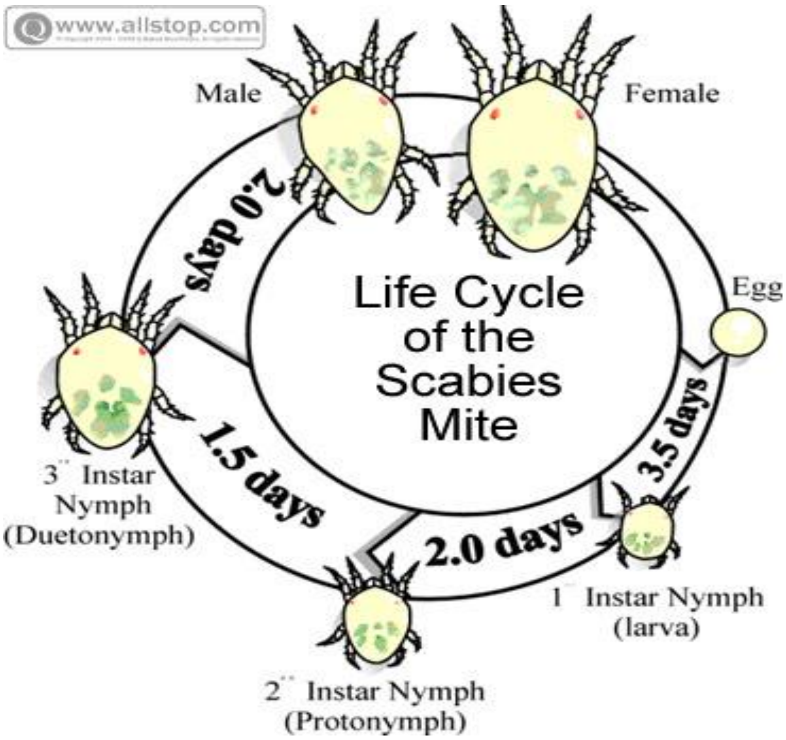

Fig. 3.1: Life cycle of the itch mite (*Sarcoptes scabiei*)

The scabies mite *Sarcoptes scabiei* var. *hominis* goes through four stages in its lifecycle: egg, larva, nymph, and adult.

Upon infesting a human host, the adult female burrows into the skin, where she deposits 2-3 eggs per day. These oval eggs are 0.1–0.15 millimetre (0.0039–0.0059 in) long and hatch as larvae in 3–4 days. Upon hatching, the 6-legged larvae migrate to the skin surface and then burrow into molting pouches (these are shorter and smaller than the adult burrows). After 3–4 days, the larvae molt, turning into 8-legged nymphs. This form molts a second time into slightly larger nymphs, before a final molt into adult mites. Adult mites then mate when the male penetrates the molting pouch of the female. Mating occurs only once, as that one event leaves the female fertile for the rest of her life (1–2 months). The impregnated female then leaves the molting pouch in search of a suitable location for a permanent burrow. Once a site is found, the female creates her characteristic S-shaped burrow, laying eggs in the process. The female will continue lengthening her burrow and laying eggs for the duration of her life.

4.0 CONCLUSION

In this unit, the body structure of a mite, morphology of the itch mite and its life cycle have been discussed.

5.0 SUMMARY

The itch mite is a parasitic arthropod that burrows into skin and causes scabies. Adults are spherical, eyeless mites with four pairs of legs. The scabies mite goes through four stages in its life cycle; egg, larva, nymph and adult. In this unit, these stages have being treated succinctly.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. Describe the body structure of a mite
2. What differentiates the body structure of a mite from that of an insect
3. Discuss the morphology of the itch mite
4. In outline from, describe the life cycle of *Sarcoptes scabei*
5. Why is the itch mite an economically important mite
6. Draw an annotated diagram of the itch mite’s life cycle

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UNIT 4 ROLES OF INSECTS AND MITES AS PESTS AND PARASITES

CONTENTS

1.0 INTRODUCTION

Insects and Mites play roles as pests and parasites in various classes of living organisms. These classes where they are found and their roles as pests and parasites are discussed in this unit.

2.0 OBJECTIVES

At the end of this unit, you should be able to;

- Identify parasitic mites in invertebrates and vertebrates
- Explain their roles as parasites in their hosts
- State insect pests and parasites as well as their roles in the various forms
- The utilization of this information in management should be clear to you at the end of this unit

3.0 MAIN CONTENT

3.1 Parasitic Mites

Parasitic mites are found everywhere and they are serious ecto-parasites of vertebrates and invertebrates. The following list contains the most important families.

3.1.1 Parasitic mites of mammals, birds and humans

Members of the parasitic mite families listed here under are those usually encountered on or in mammals, birds and even humans.

- *Family Sarcoptidae (sarcoptic mites)* - sarcoptic mange (Sarcoptidae) mites are tiny arachnids that are parasites of mammals and humans causing mange infection and the mites spend their life in the epidermis of the skin of their host causing various skin disorders
- *Family Psoroptidae (psoroptic mites)* - *Psoroptes ovis* is the well-known sheep mange mite causing serious damage to fleece and can even cause deaths
- *Family Knemidocoptidae (scaly-leg mite)*- species of this family burrow in the non-feathered areas around the beak, eyes, vent and legs of birds (ex. canaries, budgies, finches, etc.), causing tiny non-itching, wart-like lesions
- *Family Myocoptidae (myocoptic mange mite)*
- *Family Atopomelidae (fur mite)* – presence of even large numbers is usually not harmful, although itching and hair loss may occur if the host is in poor condition
- *Family Laminosioptidae* (fowl cyst, flesh or subcutaneous mites)
- *Family Pyroglyphidae (house dust mites)* - Members of this family are the well-known house dust mites causing asthma, rhinitis and allergies in humans due to an antigen they produce. They are mainly a problem along the South African coast line and especially KwaZulu/Natal where the humidity is very high
- *Family Cytoditidae (air sac mites)*
- *Family Analgidae (feather mites)*
- *Family Demodicidae (follicle mites)* - Members of this family cause symptoms in mammals characterized by itching, inflammation and other skin disorders. Blepharitis

(inflammation of the eyelids) can also be caused by *Demodex* mites. *Demodex brevis* and *D. folliculorum* live in total harmony in the hair follicles of humans

- *Family Trombiculidae (chiggers)* – members of this family are parasitic in the larval stage on vertebrates and can be vectors of diseases like typhus. The nymphs and adults are free living predators
- *Family Cheyletiellidae (walking dandruff)* - symptoms in animals vary from no signs to intense itching, scales on the skin, and hair loss. The lesions are usually on the dorsum of the animal. Symptoms in humans include multiple red, itchy bumps on the arms, trunk and buttocks. Because humans are an irregular host for the mite, the symptoms usually go away in about three weeks
- *Family Psorergatidae (sheep itch mite)* - infested flocks usually show a range of signs. Most sheep show no fleece damage at all, or may have some tufting of wool along the flanks. Very few sheep (usually one per cent) have severely damaged fleeces. Itch mites mainly affect older sheep and is rarely seen in young sheep
- *Family Myobiidae (fur mites)* - infestations of these mites may produce local and systematic effects on the host. Local effects vary from no lesion to pruritis and mild scurfiness and in serious cases to ulceration and bacterial pyoderma, chronic inflammation, fibrosis, hyperkeratosis, parakeratosis and acanthosis. Systematic effects include decreased life span and body weight
- *Family Macronyssidae (fowl or tropical rat mites*)- this family contains species of economical importance to poultry farmers and they can even be a nuisance to humans causing itching or even dermatitis. *Ornithonyssus bacoti* on rodents can even be vectors of various diseases
- *Family Dermanyssidae (red poultry mites*)- the family Dermanyssidae contains species of economical importance to poultry farmers and they can even be a nuisance to humans causing itching or even dermatitis
- *Family Rhinonyssidae (bird lung mites*) – feeds on the host's. Causes pneumonia and severe inflammation of the respiratory system; infestations are often fatal
- *Family Halarachnidae (lung and ear mites of mammals)* – reported to feed on blood, lymph and epithelial cells. Clinical symptoms are often ansent, although coughing and sneezing episodes have been reported; only massive infections are thought to be a direct cause of death

3.1.2 Parasitic mites of invertebrates

- *Family Varroidae - Varroa destructor* posses a serious threat to honey bees world wide, fortunately the South African bees apparently have a “natural” immunity against these mites
- *Family Tarsonemidae - Acarapis woodii* lives in the tracheae of bees and can cause their death, though not of economical importance yet in South Africa
- *Family Pyemotidae* - pyemotids or “straw-itch” mites can cause serious problems in insect cultures because they are very small and thus difficult to control. They poison their hosts. In humans they can cause dermatitis and allergies
- *Family Trombidiidae* - Members of this family are parasitic on arthropods in their larval stage, but nymphs and adults are free living predators.

3.2 Insect Pests

The classification of an insect as a pest is a subjective one, based on its potential damage to human purposes. Pest insects can damage agricultural crops, consume and/or damage harvested food, cause illness or unproductivity in cattle or other agricultural animals, vector human disease.

Some insects are beneficial at one stage of life and a pest at another stage, for example many lepidopterans may be serious pests as larvae, while they may be pollinators in adulthood. Some insects that are considered pests (particularly in suburbia) are actually more beneficial than pestiferous: example wasps (predate or parasitize many pest insects) or bees (the main pollinators of human food supplies).

Insects considered *pests* of some sort occur among all major living orders with the exception of Ephemeroptera (mayflies), Odonata, Plecoptera (stoneflies), Embioptera (webspinners), Trichoptera (caddisflies), Neuroptera (in the broad sense), and Mecoptera (also, the tiny groups Zoraptera, Grylloblattodea, and Mantophasmatodea). Conversely, of course, essentially all insect orders primarily have members which are beneficial, in some respects, with the exception of Phthiraptera (lice), Siphonaptera (fleas), and Strepsiptera, the three orders whose members are exclusively parasitic.

Insects are considered as pests for a variety of reasons including their;

- direct damage by feeding on crop plants in the field or by infesting stored products
- indirect damage by spreading viral diseases of crop plants (especially by sucking insects such as leafhoppers)
- spreading disease among humans and livestock
- annoyance to humans

Examples Insect Pests

- The Phylloxera plague
- Migratory locust
- Colorado potato beetle
- Boll weevil
- Japanese beetle
- Aphids
- Mosquitoes
- Cockroach
- Western corn rootworm

3.3 Parasitic Insects

Parasitic insects are very important ecologically, medically and economically. A broad definition of parasitic that includes mosquitoes and biting flies would make some 15% of insects parasitic.

Lice

Lice have been a part of human history as parasites without socioeconomic boundaries. Archaeologists have even found traces of lice on mummies. These insects are wingless, flattened and have reduced or no eyes. The eggs (nits) are glued to the feathers or hairs of the host and there are three immature forms from egg to adult. There are no free living stages and they die when separated from the host.

Bed bugs

Bugs of the Family Cimicidae are reddish brown, dosoventrally flattened bugs that are rather large (up to 8 mm long) with no wings. They are nocturnal feeders that run very fast. They generally are most active around dawn when they feed on resting hosts. Daytime hiding places include mattress seams or crack in walls or furniture. The bites may cause allergic reactions in some people but generally cause little reaction. Domestic cleanliness and residual insecticides to hiding places is effective in controlling bed bugs.

Reduvid Bugs

These bugs are vectors for *Trypanosoma cruzi*. These are large winged bugs that live in cracks and crevices of poorly constructed homes or in thatched roofs. They are not picky about the source of their blood meal and will feed on whatever is available in the habitat. Improvements in construction methods, the use of metal rather than thatched roofs and residual insecticides are effective control measures.

Fleas

Of the some 2,000 flea species, most are parasites of mammals. Historically fleas have had a great impact as transmitters of the bacteria (*Yersinia pestis*) that causes the plague. Fleas are bilaterally flattened, commonly reddish black, and wingless. The adults feed by sucking blood from the host. The larvae feed on debris and flea droppings on the bedding. Fleas are amazing jumpers. For example, common fleas can jump some 33 cm high. The oriental rat flea can jump more than 100 times its body length.

Fleas are not host specific but have preferred hosts. *Pulex irritans* is the human flea but can be found on dogs, cats, squirrels, pigs, and others. This species can transmit the plague. *Ctenocephalides canis* and *C. felis* are the common dog and cat fleas, respectively. Controlling pet parasites can be accomplished by numerous commercially available residual, topical and systemic insecticides.

Flies

Flies (Order Diptera) represent the most medically important group of insects. They cause directly or indirectly a million human deaths each year. Some flies do not kill but contribute to disfiguring, debillitating diseases of many kinds either as vectors of pathogenic organisms or as parasites.

- Black Flies

Black flies belong to the family Simuliidae and are found worldwide where the females feed on blood as well as plant nectar. Black flies are the vectors of *Onchocerca volvulus*. Mating occurs in flight, larval development occurs in running water and the flies are therefore numerous near rivers and streams. In the US and Canada, *S. venustum* are well known to fishermen and campers. Bites may produce little reaction in some people, but often small red itching wheals develop as a local reaction. Sometimes black fly fever can result which is characterized by nausea, headache, fever and swollen limbs.

- Sand flies

Most sand flies do not affect humans, but rather parasitize reptiles and amphibians. However, some do feed on birds and mammals, including humans. Females take a blood meal in addition to plant fluids. Males eat only plant juices. Most are night time feeders due to the need to avoid hot desiccating environments. They are good vectors of disease and participate in leismaniasis, bartonellosis and some viral diseases.

- Biting midges

These very small flies (less than 1 mm) are mostly daytime feeders that are most obnoxious on calm days as winds easily carry them away. Only females feed on blood. They act as vectors for various protozoal and viral disease of domestic animals.

- Mosquitoes

Some 300 species of mosquitoes have been described with at least 150 of these being in N. America. The life cycle of mosquitos requires water for the larval and pupal stages. Adult females can live for 4-5 months but during the height of the summer season they may only live a couple weeks. Males may live only for weeks to a month. Species of mosquito transmit western equine encephalitis, St. Louis encephalitis, filarial worms, yellow fever, dengue fever, eastern encephalitis and malaria.

- Tsetse flies

These flies of the *Glossina* species are found in Africa where they are vectors of sleeping sickenss. They are daytme feeders that are visually attracted to moving objects. Both sexes feed exclusively on blood, including that of humans.

4.0 CONCLUSION

This unit has treated the topic in relation to insect and mites pests and parasites. Their examples, classes and roles alike have been mentioned and discussed.

5.0 SUMMARY

Parasitic mites are grouped into two; those that parasitize mammals, birds and humans and those that parasitize invertebrates. Insect pests and parasites of economic importance include lice, bed bugs, mosquitoes, fleas, etc.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. Define the terms;

a. Pest

b. Parasite

2. Give the various classes and examples of parasitic mites in invertebrates

3. Explain the role of a named parasitic mite in humans

4. Mention the various insect pests that you know

5. Explain their roles in these states.

7.0 FURTHER READING / REFERENCES

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MODULE 2

UNIT 1 CHEMICAL PEST CONTROL METHODS AND THEIR FORMULATIONS

CONTENTS

1.0 INTRODUCTION

This unit would explain to you the meaning of chemical pest control, the history of insecticide development, the various generations of insecticides and classes or groups of pesticides.

Also, there'll be a discussion of the various types of pesticide formulations and pesticide label information.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- Explain what is meant by a pest, chemical pest control and pesticides
- Give a brief history of the development of insecticide
- State the various generations of insecticides
- Explain the classification of pesticides into various groups and their examples
- Describe the types of pesticide formulations
- Mention the essential details of a pesticide label

3.0 MAIN CONTENT

3.1 Chemical Pest Control Methods

What is a Pest?

- Pest is any animal which is noxious, destructive or troublesome to man or his interests
- A pest is any organism which occurs in large numbers and conflict with man's welfare, convenience and profit
- A pest is an organism which harms man or his property significantly or is likely to do so (Woods, 1976)
- Pests are organisms which impose burdens on human population by causing
  (i) Injury to crop plants, forests and ornamentals
  (ii) Annoyance, injury and death to humans and domesticated animals
  (iii) Destruction or value depreciation of stored products.

Chemical Pest Control: is the management of pests using chemical pesticides

Pesticides: are chemicals used to kill pests

3.1.1 History of Insecticide Development

Year	Chemicals
900	Arsenites in China (Inorganic compound)
1690	Tobacco used in Europe (Plant/natural product)
1787	Soaps used in Europe
1867	Paris Green in U.S.
1874	DDT synthesized by Zeidler
1883	Bordeau in France
1925	Dinitro compounds (First synthetic organic insecticide)
1932	Thiocyanates
1939	DDT insecticidal property discovered by **Paul Muller of Switzerland**. Paul Muller awarded Nobel Prize in 1948 for discovering insecticidal property of DDT
1941	**BHC** in France and UK (in 1942) (BHC is presently called as HCH)
1944	Parathion (**Organophosphate**) discovered by **Gerhard Schrader** in Germany
1945	**Chlordane (Cyclodian compound)** in Germany
1947	**Carbamate insecticides** in Switzerland
1962	Rachel Carson's Silent Spring appears (US) (This is not a chemical. The book ' Silent Spring' created awareness about ill effects of pesticides)
1967	First JH mimic (Juvenile Hormone mimic) used in US (Insect growth regulator)
1970	Development of synthetic pyrethroids (UK) (Fast degradation) (Effective at very low doses)
1980	Discovery of avermectins (derived from bacteria). Effective at low dose. Fast degradation.
1990	Discovery of newer groups like (1) **Neonicotinoids** (Imidacloprid), similar to natural nicotin, (2) **Spinosyns** (e.g. Spinosad) derived from actinomycet

3.1.2 Ideal Qualities of an Insecticide

An ideal insecticide should posses the following qualities;

1. Kill the target insect effectively and quickly
2. Be less toxic to natural enemies
3. Be less toxic to honey bees, soil microorganisms
4. Be less toxic to fishes and mammals
5. Less hazardous and less toxic during handling or accidental consumption by human beings
6. Quickly degradable in environment and should be less persistent (Residues should be very less)
7. Should not cause resurgence of the target insect (i.e. Increase in population of target insect) e.g. Chlorpyriphos causes resurgence of BPH on rice.
8. Should not cause outbreak of secondary pest on a minor pest by killing the natural enemies
9. Should have a complex mode of action against which resistance development will take more time. e.g. Azadirachtin from neem tree has complex action
10. Should have a longer storage life or shelf life
11. It is advantageous to select an insecticide which can kill a relatively broad spectrum of target pests
12. It should be cost effective (High benefit/Cost ratio) and safe to use (High benefit/Risk ratio)

3.1.3 Various Generations of Insecticides

S/N	Generation	Year	Compounds
1.	First generation insecticide	1939-1942	BHC and DDT
2.	Second generation insecticide	1944-1947	Organophosphates and Carbamate
3.	Third generation insecticide	1967	Hormonal insecticides, JH mimic insect growth regulators
4.	Fourth generation insecticide	1970s	Synthetic pyrethroids

3.1.4 Pesticide Groups

Pesticides are generally classified into various groups based on pest organism against which the compounds are used, their chemical nature, mode of entry and mode of action.

1. Based on organisms

a) *Insecticides* : Chemicals used to kill or control insects (eg.) endosulfan, malathion
b) *Rodenticides* : Chemicals exclusively used to control rats (eg.) Zinc phosphide
c) *Miticides* / *Acaricides* : Chemicals used to control mites on crops / animals (eg.) Dicofol
d) *Avicides* : Chemicals used to repel the birds (eg.) Anthraquionone
e) *Molluscicides* : Chemicals used to kill the snails and slugs (eg.) Metaldehyde
f) *Nematicides* : Chemicals used to control nematodes (eg.) Ethylene dibromide
g) *Fungicides* : Chemicals used to control plant diseases caused by fungi (eg.) Copper oxy cholirde
h) *Bactericide* : Chemicals used to control the plant diseases caused by bacteria (eg.) Streptomycin sulphate
i) *Herbicide* : Chemicals used to control weeds (eg.) 2,4, - D

2. Based on mode of entry

a) *Stomach poison* : The insecticide applied in the leaves and other parts of the plant when ingested, act in the digestive system of the insect and bring about death (eg.) Malathion.
b) *Contact Poison* : The toxicant which brings about death of the pest species by means of contact (eg.) Fenvalerate.
c) *Fumigant* : Toxicant enter in vapour form into the tracheal system (respiratory poison) through spiracles (eg.) Aluminium phosphide
d) *Systemic poison* : Chemicals when applied to plant or soil are absorbed by foliage (or) roots and translocated through vascular system and cause death of insect feeding on plant. (eg.) Dimethoate.

3. Based on mode of action

a) *Physical poison* : Toxicant which brings about death of an insect by exerting a physical effect (eg.) Activated clay.

b) *Protoplasmic poison* : Toxicant responsible for precipitation of protein (eg.) Arsenicals.

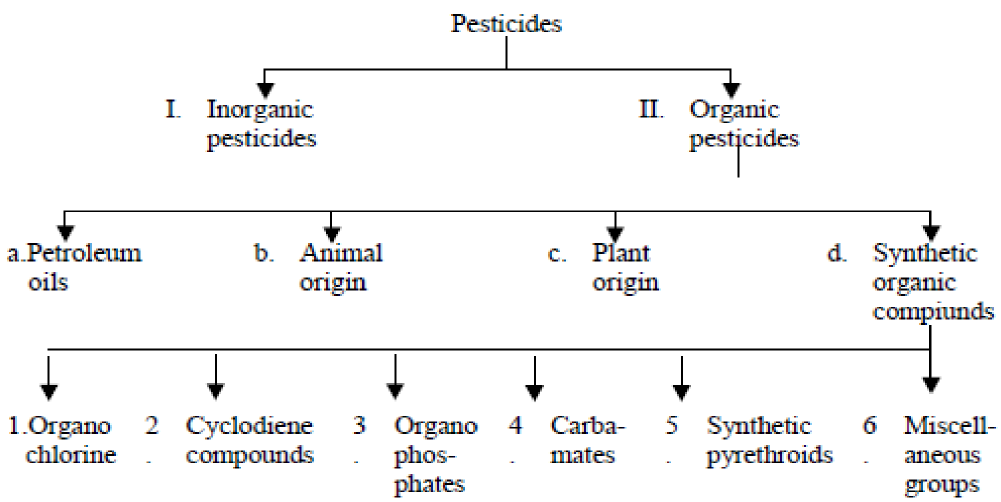
c) *Respiratory poison* : Chemicals which inactivate respiratory enzymes (eg.) hydrogen cyanide.

d) *Nerve poison* : Chemicals inhibit impulse conduction (eg.) Malathion.

e) *Chitin inhibition* : Chemicals inhibit chitin synthesis (eg.) Diflubenzuron.

4. Based on chemical nature

Classification based on chemical nature of insecticides



I. Inorganic pesticides : inorganic chemicals used as insecticides

E.g. Arsenic, Fluorine, Sulphur, lime sulphur (Insecticides), zinc phosphide (Rodenticide)

II. Organic pesticides : organic compounds (constituted by C, H, O and N mainly)

a. *Hydrocarbon oil (or) Petroleum oil* – eg. Coal tar oil, kerosine etc.,

b. *Animal origin insecticides* – eg. Nereistoxin extracted from marine annelids – commercially available as cartap, padan.

c. *Plant origin insecticides* : Nicotine from tobacco plants, pyrethrum from *Chrysanthemum* flowers, Rotenoids from roots of *Derris* and *Lonchocarpus,* Neem – *azadirachtin*, *Pongamia glabra*, Garlic etc.,

d. *Synthetic organic compounds* : These organic chemicals are synthetically produced in laboratory.

Table 5: 1: Synthetic Organic Compounds and Their Examples

S/N	**Group**	**Examples**
i.	Chlorinated hydrocarbon (or) organochlorines	Eg. DDT, HCH, Endosulfan, Lindane, Dicofol (DDT, HCH banned)
ii.	Cyclodienes	Eg. Chlordane, Heptachlor (Banned chemicals)
iii.	Organophosphates : (Esters of phosphoric acid)	Eg. Dichlorvos, Monocrotophos, Phospamidon, Methyl parathion, Fenthion, Dimethoate, Malathion, Acephate, Chlorpyriphos
iv.	Carbamates: (Derivatives of carbamic acid)	Eg. Carbaryl, Carbofuran, Carbosulfan
v.	Synthetic pyrethroids ; (Synthetic analogues of pyrethrum)	Eg. Allethrin, Cypermethrin, Fenvalerate
vi.	Miscellaneous compounds	a. *Neonicotinoids* (Analogues of nicotine) eg. Imidacloprid b. *Spinosyns* (Isolated from actinomycetes) eg. Spinosad c. *Avermectins* (Isolated from bacteria) eg. Avermectin, Vertimec d. *Fumigants* : Eg. Aluminium phosphide, Hydrogen cyanide, EDCT

3.2 Pesticide Formulations

Pesticides are not usually applied in pure form (active ingredient) since they are highly toxic and quantity available for application is low and hence they are diluted with inert materials like talc (or) with water combining with other materials such as solvents, wetting agents, stickers, etc. The final product is the formulated pesticide and it is ready for use.

3.2.1 Types of Formulations

According to the mode of application, the types of formulation are as follows:

I. For dry application directly from container ;

1. *Dusts (D)* : The technical material (active ingredient) is mixed with a carrier such as clay (attapulgite, Kaolin, ash), organic flour (wood bark), pulverised minerals (sulphur, talc, lime, gypsum). Particle size will be less than 100 and it should pass through 200 mesh sieve. Dusts are cheaper and easy to use. However, they are least effective and cause wind drift leading to poor deposit on surface; they are highly toxic to beneficial insects.

2. *Granules (G)* : Granules are prepared by applying liquid insecticides to coarse particle of porous material like clay, corn cobs (or) walnut shells. The amount of active ingredient ranges from 2-10 per cent. They are much safer to apply than dusts.

II. For spraying after mixing with water ;

1. *Wettable Powders (WP)* : It consists of active ingredient mixed with inert dust and a surfactant that mixes readily with water and forms a short - term suspension. WPs are much more concentrated than dusts, containing 15 to 95% active ingredient. Frequent agitation is required to keep the insecticides in suspension. WPs usually cause less phytotoxicity than ECs. WPs should never be used without dilution.

2. *Emulsifiable Concentrates (EC)* : It consists of a toxicant, a solvent and a emulsifier with a stabilizing agent. When EC is mixed in water, it gives emulsion - droplets of oil containing the insecticide dispersed in water. Emulsifier turns the water-insoluble toxicant to water-soluble and it yields a stable milky solution when diluted with water. When applied, the solvent evaporates quickly leaving the toxicant from which water also evaporate.

3. *Soluble Powders (SP)* : Soluble powder consist of finely ground solid material which dissolve in water or some other liquid forming true solution.

4. *Flowable (F)* : Flowable is a pesticide formulation in which the active ingredient is wet milled with a clay diluent and water. Flowables must be constantly agitated to prevent the insecticide from coming out of suspension and settling.

5. *Ultra Low Volume Concentrates (ULV)* : They are special kind of high concentrate solutions and are applied without dilution with special aerial or ground equipment to produce extremely fine spray.

III. For application as gas or vapour

1. *Fumigants* : Fumigants are pesticides in the form of poisonous gases that kill when absorbed or inhaled. Most of the fumigants are liquid and are mixtures of two or more gases.

2. *Smoke generators* : They are used in the form of coil-like strips containing pyrethrum, oxidant and wood dust for the control of mosquitoes. When ignited, these coils release vapours.

3. *Aerosols* : Aerosol contains a small amount of pesticide that is driven through a fine opening by a chemically inactive gas under pressure when the nozzle is tiggered or by burning toxicant or vapourizing it with that. The toxicant is suspended as minute particle (0.1 - 50 w/w) in air as a fog or mist. It consists of toxicant (2%), solvent (10%), knockdown agent (2%) and propellant (86%).

Other Formulations ;

1. *Poison bait* : These are mixtures of an insecticide with food attractive to the target pests.

2. *Seed dressers* : These consist of an active ingredient in carrier material with an adhesive for better coating of the chemical on the seeds.

3. *Tablets* : It consist a toxicant, a carrier to prevent flamability.

4. *Insecticide paints and polishes* : Toxicant is produced in the form of paint/polish and can be applied as such by using a brush.

5. *Encapsuled fumigants* : The fumigant is impregnated in some inert material and sealed in plastic containers. Cut open the plastic container before use.

3.2.2 Pesticide Label Information

Every pesticide container has a label affixed on it with a leaflet. The label gives information of the pesticide in the container. The leaflet contains information on directions to use, warnings, disposal and storage.

Both the label and leaflet are statutorily required under the Insecticide Act, 1968. The following information must be furnished on the label.

1. Name of the pesticide (Brand name, Trade name, Common name).
2. Name of the manufacturer and address
3. Registration number
4. Kind and name of active ingredient and their percentage
5. Types of formulation
6. Net content by weight
7. Batch number (assigned by manufacturer)
8. Date of manufacture
9. Expiry date
10. Antidote statement
11. Warning symbols and signal (warning symbol is of diamond shaped consisting of two triangles with a colour in the lower triangle and a signal in the upper triangle).

Table 5.2: Information that should be on Pesticide labels

Category	Classification of the Insecticides	Symbol and Word to be Printed on the Upper portion of triangle	Colour of the Identification band on the lower portion of the triangle	Acute toxicity I.D mg/kg body weight	
				Oral route	**Dermal route**
I.	Extremely toxic	a)Keep out of the reach children b)If swallowed or if symptoms of poisoning occur, call immediately	Bright red	1 -50	1 – 200
II.	Highly toxic	Keep out of the reach children	Bright yellow	51 – 500	201 – 2000
II.	Moderately toxic	Keep out of the reach children	Bright blue	501 – 5000	2001 – 20,000
IV.	Slightly toxic		Bright green	5000	20,000

The leaflet must furnish the following ;

1. Name of the pests, weeds and diseases against which the chemical may be used
2. Direction for use.
3. Warning and cautioning statement, symptoms of poisoning, antidotes and first aid.
4. Direction for storage, careful handling and method of disposal.

4.0 CONCLUSION

Chemical pest control methods is basically concerned with the types or categories of pesticides and their target organisms or pests. The various generations of insecticides reveals the research being done on insecticides. Pesticide formulations are of various types depending on their use or mode of applications. All these points have been highlighted in this unit.

5.0 SUMMARY

This unit treats the meaning of a pest (an organisms which harms man or his property significantly or is likely to do so), chemical pest control (the use of chemicals to manage or control pests). These chemicals termed pesticides are divided into various groups or classes based on organisms (insecticides, miticides, rodenticides, etc.), based on mode of entry (stomach poison, systemic poison, contact poison, etc.), based on mode of action (physical poison, nerve poison, respiratory poison, etc.) and based on chemical nature (inorganic and organic pesticides).

Pesticide formulations are the various forms in which a pesticide is prepared for use or application. The types of pesticide formulations include dusts, granules, wettable powders, emulsifiable concentrates, soluble powders, fumigants, aerosols, etc. The contents of a pesticide label include; Name of the pesticide (Brand name, Trade name, Common name)., Name of the manufacturer and address, Registration number, Kind and name of active ingredient and their percentage, Types of formulation, expiry date, etc.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. Explain the term Chemical Pest Control

2. Write briefly on the development of insecticides and the various generation sof insecticides

3. What are the essential qualities of an insecticide?

4. State the classes of pesticides with examples

5. What is meant by Pesticide formulation?

6. Describe the types of pesticide formulations that you know

7. Mention the contents of a pesticide label

7.0 FURTHER READING / REFERENCES

http://www.culturaapicola.com.ar/apuntes/libros/20_Principos_aplicados_entomologia.%20(1).pdf – Principles of Applied Entomology

UNIT 2 METABOLISMS AND BEHAVIOUR IN THE ENVIRONMENT

CONTENTS

1.0 INTRODUCTION

Organic insecticide chemicals continue to be important agents for the control of insect pests that attack or annoy man, his useful animals and his crops. To a varying degree, man and his useful animals encounter these chemicals in their manufacture, in their application to crops, soils and surfaces harbouring pests, in handling and contacting materials treated with them, and in transportation, use and/or consumption of food, feed or fibre containing their residues. Since these chemicals are, by their very nature, toxic and since many of them degrade to toxic materials, it is important in the interest of efficiency and safety to elucidate the biochemistry of their degradation in plants, mammals and insects. Therefore, it is not surprising that, as a result of the work done in the past two decades, much information now exists on the metabolism of organic insecticide chemicals in various test organisms. For various reasons, such data do not always concern insecticide chemicals that pose the greatest hazard or that are the ones most used; rather, much of it pertains to chemicals that are peculiarly amenable to metabolism studies because they are capable of analysis.

Pesticides are an essential element of agriculture production. Increased use of pesticides has greatly aided agricultural production, decreased losses of stored grains, and has generally improved man's welfare. However, pesticide usage may lead to undesirable residues as trace contaminants of food, the environment and living tissues. Pesticides are known to move from treated agricultural areas into the broader environment, then they can reach to the non-target organisms. Once pesticides enter the atmosphere, they may be transported long distances. The escape of these chemicals into the atmosphere represents an economic loss to the user, inefficient control of pests, and introduction of possible environmental contamination.

2.0 OBJECTIVES

At the end of this unit, you would be able to:

- Mention some important advancements in the study of the metabolism of insecticides
- Illustrate the pathways of metabolism of an insecticide chemical in living organisms
- Discuss the metabolism of various classes of insecticides in living organisms
- Describe the properties of pesticides which affect their behaviour in the environment
- State some environmental characteristics which could affect pesticide behaviour

- Explain the fate of pesticides in the atmosphere, aquatic ecosystems, plant-soil system and in living organisms

3.0 MAIN CONTENT

3.1. Metabolism of Insecticides in Living Organisms

Work on metabolism of insecticide chemicals inherently has to wait until suitable qualitative and quantitative methodology is available. Fortunately, proper tools and concepts are now available and, as a result, the knowledge about the metabolism of insecticide chemicals is considerable and is continuing to increase at a rapid pace.

The important advancements in this field include:

(1) the use of radioactive compounds as tracers and for quantitation;
(2) employment of a wide variety of chromatographic techniques for resolution and isolation of metabolic products;
(3) perfection of ultraviolet, infrared, nuclear magnetic resonance (NMR) and mass spectroscopy accessories for identifying very small amounts of such products;
(4) improvements in synthesis procedures for authentic compounds needed to confirm the tentative characterization of metabolic and degradation products;
(5) development of active mammalian, insect and plant *in vitro* enzyme systems that reproduce, at least in part, the reactions occurring in the living organism, and
(6) accumulation of a body of related literature providing analogies appropriate for predicting the possible metabolic pathways involved.

All organic insecticide chemicals, to a varying degree, metabolize in living organisms. The extent and nature of the biotransformations vary with the species and the chemical, the time of residence in the organism being an important factor; in some cases, a given amount of certain chemicals metabolizes completely in a matter of minutes while other chemicals require hours or months. Thus, certain complex insecticide chemicals are readily metabolized in an organism while some relatively simple ones are amazingly resistant to biodegradation. The biotransformations mentioned are the result of various enzyme systems or of normal chemical reactions. In mammals, these systems are frequently localized in the microsomal fraction of liver, while in insects the comparable system resides mainly in the fat body. The microsomes involved are generally separable into a discrete centrifugal fraction. The oxidative attack on insecticide chemicals normally requires the presence of a cofactor such as nicotinamide-adenine dinucleotide phosphate in its reduced form (NADPH), and of oxygen. Apparently such microsomal enzymes catalyze the conversion of molecular oxygen from air to form an "active oxygen" which complexes with cytochrome P-450 and which is the attacking species in certain transformations. Some insecticide chemicals, particularly the chlorinated hydrocarbons, are inducers of these microsomal mixed-function oxidases in certain mammalian species. Also, the metabolism of some insecticides by the mixed-function oxidases is inhibited by certain methylenedioxyphenyl compounds and by other materials which, in themselves, are substrates for the enzyme system. There is limited evidence indicating that plants contain an oxidative system similar to the NADPH-dependent mixed-function oxidases of insects and mammals, but little information is available on this point. Of course other reactions are catalyzed by different enzymes such as esterases, phosphatases, amidases, dehydrochlorinases, etc.

The manner and rate of metabolic attack on an insecticide chemical vary with the species, strain, sex, age and other characteristics of an organism, with the presence or absence of certain additional chemicals (that act as synergists, antagonists, inducers, ete.) and, particularly, with the variety of functional or reactive groups available in the molecular structure of these chemicals. In the attack (which generally is enzymatic), ester and amide groups are hydrolyzed; ether groups are cleaved; hydroxylation occurs on aromatic rings and on *C*-alkyl and *N*-alkyl substituents; unsaturated bonds are altered by oxidation; thioethers are oxidized, and phosphorothionates are converted to phosphates with loss of sulfur. N-Alkyl-groups are removed by hydroxylation and oxidation; halogens and sulfur are removed or substituted; nitro-groups are reduced; isomerization is induced; rings are opened, and acidic or alcoholic functions are conjugated. The attack is sometimes altered by small changes in chemical structure of the insecticide; so, results cannot always be interpolated from one compound to a closely related analog. The attack generally produces detoxification, but at times gives rise to degradation products that have a toxicity equal to or greater than that of the parent compounds. If hydrolysis of esters takes place, detoxification generally results.

Toxic metabolites sometimes result from pathways which involve oxidation or hydroxylation if the attack does not destroy the toxophoric grouping.

The attack on an insecticide chemical frequently takes place at more than one point on the molecule, either by way of separate pathways or as sequential reactions. Thus, the metabolism sometimes involves alternate pathways, as illustrated in the following diagram, involving a series of metabolites (some being transitory):

Chemical	→	Metabolite A	→	Metabolite B
↓		↓		↓
[Metabolite C]	→	[Metabolite D]	→	[Metabolite E]

Insects and plants frequently metabolize by one major pathway and mammals by another, the rates and extent varying in each case, but there are important exceptions. The processes in plants are, in most cases, slower than in animals, if similar mechanisms are involved; most mammals have better degrading enzyme systems than those found in insects and plants. The pathway followed depends on the balance of enzymes of various capabilities present in the species of interest. The biotransformation mechanisms in mammals and insects are often deduced from the nature of the excreted products, whereas in plants they are deduced from the persisting metabolites, conjugated or not. Enzymatic studies are important in understanding the mechanisms involved and the chemistry of unstable or transitory intermediates encountered.

The phenomenon of selective toxicity is often the result of detoxification and activation changes in an insecticide chemical, taking place at different rates in susceptible and in resistant or tolerant species or strains, the susceptible one hopefully being the pest. The site(s) of metabolic attack and the metabolic pathways are usually the same for the susceptible and resistant strains or species, but the rates of attack or reaction at various positions in the molecule are different. In this regard, the presence of two or more sites on the molecule which are susceptible to attack sometimes provides the "opportunity factor" needed for selective toxicity because the rates of attack or metabolic reaction at these sites vary from organism to organism. The presence of barriers to penetration of an insecticide chemical into an organism and into the ultimate site of toxic action can be a major factor in selective toxicity because such barriers increase the opportunity or time available for biotransformations of the chemical before it reaches the target enzyme or binding site.

Metabolism investigations now follow a careful experimental design directed toward defining the total physical and chemical fate of the compound. This is a departure from past practice, where only certain potential metabolites were sought without regard to a complete definition of the total reactions involved. Therefore, the data from early work are deficient in several respects, especially in regard to conjugated metabolites. This is important because conjugates of metabolic products containing the intact toxophoric grouping, such as in plants, represent potential toxic materials if ingested by an animal capable of splitting the conjugate. It should be realized that conjugation takes place to some degree, especially with compounds containing alcohol, phenol or carboxylic acid groups, in those cases where the compound susceptible to conjugation is not immediately excreted or stored and is relatively stable to other detoxification mechanisms.

The *in vivo* metabolism investigations with insecticide chemicals are aided by in vitro biochemical studies. In vitro experiments permit the pinpointing of possible enzymatic reaction mechanisms and products. *In vivo* studies make possible quantitative consideration of the expected reaction in the presence of possible competing points of attack, reactions, components and pathways.

In addition to toxicological implications, metabolic studies are important because they form the basis for the development of analytical methods for the determination of toxic residues in crops. Such data are needed in connection with establishment of residue tolerances and levels considered to be "negligible residue", and in the interpretation of pharmacological data leading to the establishment of a "no-effect" level.

3.1.1 Botanicals

i) Nicotine

The fate of nicotine in mammals, including man, is well known as a result of the need for this information in medicine, by health services and for safety considerations.

The metabolic attack on nicotine by the mammalian liver includes;

(a) methylation of the pyridyl nitrogen, to form isomethylnicotinium ion,
(b) demethylation of the nitrogen in the five-membered ring to form nornicotine,
(c) hydroxylation of a carbon atom adjacent to this nitrogen.

The hydroxylation attack is the major one leading to the opening of the pyrrolidine ring and reclosing of the ring to form cotinine and, ultimately, to form norcotinine, hydroxycotinine and 3-pyridylacetic acid, among other metabolites. Insects and plants attack and metabolize nicotine in much the same way as mammals, yielding cotinine and other metabolites, the major sites of attack varying with the species. It is interesting to note that the pathway for nicotine biosynthesis in plants is well understood.

ii) Rotenone

While rotenone is one of the oldest insecticide chemicals, the main metabolic attacks on it have only recently been elucidated, the work awaiting the synthesis of carbon14-labelled rotenone with high specific activity. The main initial attacks in rotenone metabolism, under both in vitro and in vivo conditions in houseflies and mammals, involve; hydroxylation at the B-C ring juncture to give rotenolone I and II, hydroxylation of the methyl group in the isopropenyl side chain to give 8'-hydroxyrotenone, and epoxidation of the double bond in this side chain, followed by epoxide cleavage to give 6',7'-dihydro-6',7'-dihydroxyrotenone. The hydroxylation at the 12a-position of rotenone reduces the toxicity, but hydroxylation in the isopropenyl group yields a product of equivalent high toxicity. While still unidentified, the polar metabolites that occur in urine and other excretions probably consist, in part, of conjugates of the metabolites just mentioned. Definitive studies have not been made on the metabolism of rotenoids other than rotenone itself, but their metabolism is probably by pathways considerably different from those noted here because all of them lack the isopropenyl group. The fate of rotenoids in plants remains to be determined, but considerable information exists in regard to their biosynthesis.

iii) Pyrethroids

As in the case of rotenone, the sites of metabolic attack on the pyrethroids have only recently been elucidated, the work awaiting synthesis of the appropriate radioactive compounds labelled with carbon^{14} in the acid and in the alcohol moieties. Contrary to earlier indications, it is now clear that hydrolysis plays a minor role, if any, in the metabolism of several pyrethroids in houseflies. The main metabolic attack, under in vitro and in vivo conditions, on allethrin by houseflies involves omega oxidation of the transmethyl group of the isobutenyl side-chain to a carboxylic acid group. Initial hydroxylation of the methyl group is followed by further oxidation of the resulting hydroxymethyl group, via the aldehyde, to the acid. Both the alcohol and acid are susceptible to conjugation and excretion. This pathway, which leaves the ester link intact, appears to be common to other pyrethroids (such as pyrethrin I, phthalthrin, and dimethrin). A number of unidentified minor metabolites accompany the major acid metabolite, and these products probably result, in part, from omega-cfc oxidation. The metabolism is more complex in mammals but it is known in adequate detail only in the case of phthalthrin which suffers considerable hydrolysis and for which several of the products from the alcohol moiety are identified. It is possible that pyrethrin II arises in chrysanthemum flowers by oxidation of pyrethrin I followed by methylation of the carboxylic acid product.

3.1.2 Methylenedioxyphenyl Synergists

Methylenedioxyphenyl synergists, mainly used to enhance the insecticidal activity of pyrethrum, metabolize rapidly in mammals and more slowly in houseflies. Piperonyl butoxide, Tropital and sulfoxide, in common, suffer initial hydroxylation probably to give the unstable hydroxymethylenedioxyphenyl derivative which, in turn, decomposes to give the corresponding catechol and formate, the latter oxidizing to carbon dioxide. This pathway predominates over alternate pathways in living mice and in mouse-liver microsome systems. Piperonyl butoxide and Tropital also hydroxylate on the alpha carbon of the ether side chain, ultimately forming the respective piperonylic acid derivatives; in the case of Tropital this is the predominant pathway, while in the case of piperonyl butoxide the formate- and catechol-producing pathway is the main one. Sulfoxide undergoes hydroxylation and oxidation at the sulfur, yielding a sulfone; it also produces a number of unidentified products. Most of the metabolic products (which are phenols, alcohols and acids) form conjugates readily. When both compounds are present at the same time, the metabolism of synergists competes with the metabolism of pyrethroids in a manner that spares the detoxification of the pyrethroid.

3.1.3 Chlorinated Hydrocarbons

The group of insecticide chemicals collectively called "chlorinated hydrocarbons" contains compounds which show great variation in degree of metabolism and persistence, and for which the availability of metabolism data varies from abundant to meagre. Most of these compounds and some of their metabolites are sparingly soluble in water, store avidly in fatty tissue and, to a varying degree, are excreted in the feces. The metabolites that are hydrophilic are excreted in the urine of mammals. In general, the metabolic attack on these compounds occurs in the mammalian liver, and in the fatbody or cuticle of insects. Their metabolism characteristics sometimes play a major part in the development of resistant or tolerant insect strains.

i) DDT and Methoxychlor

DDT and methoxychlor undergo dehydrochlorination in the trichloroethane group forming an ethylene bond such as that in DDE. DDT also suffers reductive dechlorination at the trichloromethylngroup to form DDD (TDE) and hydroxylation at the tertiary carbon to form an alcohol (dicofol) which sometimes metabolizes to dichlorobenzophenenone. In mammals, DDT and methoxychlor suffer a sequence of reactions, involving dechlorination, dehydrochlorination and reduction, followed by hydration and oxidation to form the respective disubstituted acetic acids, such as DDA (from DDT). In addition, methoxychlor apparently undergoes O-demethyktion, a reaction which probably contributes to its low mammalian toxicity. In many insect species, the main terminal metabolic product of DDT is DDE but in others, such as fruit flies, it is dicofol; in still others, unidentified polar compounds are formed. DDD metabolism generally follows the DDT pathway. DDA and DDE are the main excretory products of DDT in mammals, along with some DDD (the precursor of DDA) and minor amounts of unidentified hydrophilic products. The reductive dechlorination is apparently catalyzed by reduced porphyrins. It is of interest that o,p'-DDT, an impurity in technical DDT, isomerically converts in rats to p,p'-DDT. All in all, the metabolic attack on DDT and methoxychlor is varied, complex and not completely clear, at least in some organisms.

ii) Lindane

Lindane (γ-BHC) degrades rapidly in houseflies and mammals but only after initial conversion to a thiol conjugate. Glutathione (GSH) is probably the thiol donor in this case. The thiol conjugate cleaves, forming a pentachlorocyclohexene, or, alternatively, it apparently degrades to all six isomers of dichlorophenyl mercapturic acid. The pentachlorocyclohexene metabolizes, in sequence, to tetra- and trichlorobenzenes and, ultimately, to trichlorophenols (which are conjugated). A variety of unidentified hydrophilic metabolites also form. While less defined, plants probably metabolize lindane to pentachlorocyclohexene by the same general pathway.

iii) Chlorinated Methano-Bridged Cyclohydrocarbons (Cyclodienes)

Until recently, the epoxide forms of the so called chlorinated cyclodienes were considered to be stable in metabolizing systems. However, these compounds, too, suffer some degree of biotransformation involving hydroxylation, dechlorination and oxidation. While some of the metabolic products have been identified, a great many remain unknown, most of them being hydrophilic. Alpha-chlordan converts to hydroxy derivatives involving replacement of one or both chlorines, in one of the rings, in mammals and insects. In all species, heptachlor rapidly converts to the equally toxic epoxide, and subsequently the epoxide slowly degrades in some mammals to a monohydroxy derivative by replacement of a chlorine. The epoxide stores avidly in fatty tissue. Isobenzan (Telodrin) metabolism in rats and mosquito larvae involves hydroxylative removal of the two chlorine atoms in the oxygen-containing ring, to give the unstable acetal which rapidly converts to the lactone or to intermediate conjugates which, in rats, are excreted in the feces and, mainly, in the urine. Telodrin stores, as such, in fatty tissue. Endosulfan hydrolyzes (a) to endosulfan alcohol and oxidizes to endosulfan sulfate, in insects, plants and mammals; unidentified hydrophilic metabolites also form.

Aldrin and isodrin rapidly epoxidize in all organisms to form dieldrin and endrin, respectively; in this respect, the biotransformation of aldrin and isodrin is similar to that of heptachlor. In insects and mammals, dieldrin suffers opening of the epoxide ring to produce one of the optical isomers of trans-6,7-dihydroxy-6,7-dihydroaldrin; also, it suffers hydroxylation, possibly at the juncture of the two dimethano-bridged rings to form an alcohol, and is dechlorinated and oxidized to produce the pentachloro-bridged ketone. Under similar circumstances, endrin isomerizes in plants to form the hexachloro- bridged ketone. Both dieldrin and endrin store avidly in fatty tissue and produce several unidentified hydrophilic metabolites. All in all, some of the metabolic pathways of the chlorinated cyclodienes still remain unknown, especially in plants; however, work in this area is in progress.

Toxaphene metabolizes readily by an unknown pathway to non-toxic products yet to be identified. Since the technical material is a complex mixture of related compounds, adequate metabolism studies on it are very difficult. Excessive doses lead to storage in fatty tissues.

3.1.4 Organophosphorus Compounds

In marked contrast to some of the groups of insecticide chemicals already considered, much information exists in regard to the metabolic attack on organophosphorus compounds in mammals, insects and plants. Thus, the metabolic pathways and terminal residues for these chemicals are quite well understood. This favourable situation is largely the result of the important emphasis on organophosphorus chemistry during the period around the Second World War and of the early availability of phosphorus^{32}-labelled insecticide chemicals. Organophosphorus compounds are somewhat special because some of them can suffer both activation and detoxification during metabolism in a variety of organisms. Practically all of them are metabolically converted to inhibitors of esterases, including acetylcholinesterase. Most of them are readily attacked by enzyme systems present in mammals, plants and insects, especially those that promote hydrolytic reactions or that substitute oxygen for thiono-sulfur.

i) Organophosphates and Organophosphonates

This category of compounds is vast, and mention is made here of only certain ones that are commercially important or that illustrate various sites of metabolic attack. Insecticidal pyrophosphates include tepp, a tetraethyl derivative which hydrolyzes easily by enzymatic and nonenzymatic means, and schradan, the very stable tetra(dimethylamidate) derivative. The metabolic attack on tepp is by hydrolysis of the pyrophosphate bond. Schradan suffers this hydrolysis also but only after oxidative attack which includes *N*-demethylation via *N*-oxide or *N*-hydroxymethyl intermediates.

The substituted-vinyl phosphates vary in hydrolytic stability from quite unstable ones, like dichlorvos, to very stable ones like Bidrin. In rats, dichlorvos rapidly hydrolyze to give dichloroacetaldehyde, which excretes as conjugates of dichloroethanol, along with the phosphoric acids that result from a combination of *O*-demethylation and hydrolysis. It is possible that transmethylation with GSH is a factor in the former reaction. Chlorfenvinphos hydroxylates at the ethyl group to give acetaldehyde, an unusual form of *O*-dealkylation. The cis-isomer of mevinphos suffers extensive *O*-demethylation in mice in a GSH-dependent reaction, whereas hydrolysis to dimethylphosphate is the principal reaction with the trans-isomer. In plants, carbomethoxy hydrolysis also takes place. The more stable analog, Bidrin, is attacked in plants, insects and mammals by hydrolysis and *O*-demethylation, to give a variety of phosphoric acid derivatives. Toxic intermediates result from hydroxylation and *N*-demethylation, yielding *N*-hydroxymethyl Bidrin, des-*N*-methyl Bidrin (Azodrin), *N*-hydroxymethyl Azodrin, and, finally, Bidrin amide. Phosphamidon undergoes hydrolysis in mammals to ά-chloro-*N*,*N*-diethylacetoacetamide and oxidative *N*-deethylation to des-*N*-ethylphosphamidon and phosphamidon amide, both compounds being toxic. Removal of the chlorine yields deschlorophosphamidon amide. Plants also deethylate and hydrolyze phosphamidon. It is of interest to note that only the *N*-alkylamide-containing vinyl phosphates give toxic metabolites.

Naled and trichlorfon are potential precursors of substituted-vinyl phosphates. Naled cleaves to a mixture of phosphoric acid derivatives, or debrominates to dichlorvos which, in turn, metabolizes as described above. Trichlorfon undergoes cleavage at two places to yield dimethyl- and methylphosphoric acids, the released trichloroethanol being excreted in mammals as a glucuronide. While it takes place only to a small extent, trichlorfon dehydrochlorinates and rearranges to form the vinyl phosphate, dichlorvos, probably by a non-enzymatic mechanism.

In mammals, Ruelene hydrolyzes at the two P-O-C bonds and at the P-N bond, forming a variety of phosphorus acids which are excreted.

Although it is not an insecticide, tri-*o*-cresyl phosphate (TOCP) potentiates the toxicity of many compounds such as malathion and dimethoate. This results from hydroxylation of one methyl group, leading to cyclization and formation of a saligenin cyclic phosphate which inhibits the carboxylic esterases and amidases involved in hydrolytic detoxification of the potentiated compounds.

ii) Organophosphorothionates and Organophosphonothionates

The general comments made above in regard to the vast number of organophosphates and organophosphonates that have been investigated apply equally here. Therefore, only a limited number of compounds are considered in this category.

Thionophosphorus compounds are more stable to cleavage by esterases than the corresponding phosphates; thus, there is an increased likelihood of attack by mechanisms other than phosphoryl cleavage by esterase action. Each of these compounds undergoes oxidation of the thiono grouping, a reaction critical in their conversion to anticholinesterase agents, but the yield of the conversion is generally low. They also cleave, in varying ratios, at almost every type of ester or amide grouping present in their structures. Each phosphorothioic acid derivative liberated oxidizes to the phosphate analog and, frequently, degrades to inorganic phosphate ion. (Only major initial cleavage sites are considered here.)

Parathion is oxidized to paraoxon, apparently with some concomitant hydrolysis of the phosphorothionate to yield para-nitrophenol and *O,O*-diethyl phosphorothioic acid. Rumen fluid results in reduction of the nitro group to a non-toxic amino derivative. Similar types of oxidative and hydrolytic pathways are involved with methyl parathion (the dimethyl analog of parathion), Sumithion, runnel, bromophos, Chlorthion, diazinon, dioxathion, EPN, Dursban and azinphosmethyl. *O*-Demethylation is an additional important pathway in metabolism of the dimethylphosphorothionates, probably via the GSH-mediated transmethylation mechanism, at least in mammals. Imidan gives, among other metabolites, phthalamic and phthalic acids, probably by a series of hydrolytic reactions. Thiioethercontaining compounds such as phorate have the additional site of divalent sulfur which is oxidized to the sulfoxide and sulfone derivatives. These reactions also occur with disulfoton, demeton, oxydemetonmethyl, fenthion, carbophenothion, Methyl Trithion and other sulfides or sulfoxides. Cleavage of the phosphorothiolate grouping to release a thiol leads to methylation of the thiol and subsequent oxidation of the methylthio-product to sulfoxides and sulfones; this sequence of reactions is known with menazon and dyfonate. (This point needs to be checked out with other mercaptans released by the hydrolysis of other phosphorothiolates.) Each ester and amide group of malathion and dimethoate are cleaved, in reactions which vary with the organism and which contribute to the selective toxicity of these compounds. It is of interest to note that these compounds are altered in toxicity by other "potentiating" organophosphates which cause an imbalance in the respective metabolic pathways by selective inhibition of certain hydrolyses. Coumaphos, in addition to the expected reactions, probably undergoes an opening of the lactone ring to give a water-soluble product which is excreted; this reaction may not be enzymatically mediated. In plants, Abate suffers the metabolic attack and biotransformations anticipated from the above discussion, the main one being oxidation to the sulfoxide followed by hydrolysis and formation of glucosidic conjugates; minor pathways involve oxidation of one or both of the thiono sulfurs and oxidation to the sulfone.

3.1.5 Methyl- and Dimethyl Carbamates

Metabolism of the carbamic acid ester insecticide chemicals differs from that of phosphoric acid esters even though both act as cholinesterase inhibitors. This is so because the methyl- and dimethylcarbamoyl groups are surprisingly stable to hydrolysis in living organisms. Although hydrolysis is involved, the major metabolic attack consists of hydroxylation and oxidation, followed by conjugation of the hydroxylation products. Just as phosphorylation of certain tissue proteins occurs in mammals with the organophosphates, there is evidence that some carbamoylation takes place in mammals in the presence of carbamates.

Carbaryl converts in plants, houseflies and rats into four metabolites resulting from hydroxylation attack on the *N*-methyl group and on the ring and epoxidation followed by epoxide cleavage on the non-phenolic ring; each of these initial oxidation products subsequently conjugates. The conjugates are excreted as sulfates and glucuronides in mammals, but they persist as glycosides in plants. Some hydrolysis takes place in both plants and rats, and the released 1-naphthol suffers rapid metabolism. Dogs handle carbaryl in a different manner, not involving liberation of 1-naphthol or hydroxylation of carbaryl. In plants, houseflies and rats, Baygon hydroxylates on the *N*-methyl group, the ring and the isopropoxy group, the latter attack resulting in formation of acetone by *O*-depropylation. Again, hydrolysis appears to be a minor pathway and rapid conjugation of the initial hydroxylation products takes place. There is evidence that Landrin, Furadan and Banol hydroxylate in various organisms at the N-methyl, ring-methyl or ring-methylene substituents, with subsequent conjugate formation; in Furadan, the hydroxylated methylene group in the ether-containing ring is oxidized to a ketone group. Banol apparently is excreted in rat urine as the *N*-glucuronide of the intact carbamate. Zectran and Metacil undergo initial oxidation-hydroxylation in plants and mammals of each *N*-methyl group, forming *N*-formamide intermediates in the *N*-demethylation of the dimethylamino group. In plants and insects the oxime carbamate, Temik, undergoes thioether oxidation to the sulfoxide and sulfone, with and without hydrolysis, and in cotton the liberated oxime moiety degrades slowly to the nitrile-sulfoxide and other products. Rats dosed with Temik excrete the corresponding sulfoxide, the oxime sulfoxide and unidentified acids in the urine. The dimethylcarbamate, dimetilan, suffers *N*-methyl hydroxylation in successive stages and, finally, *N*-demethylation; hydrolysis takes place to an extent depending on the organism or system involved.

Resistance of selected housefly strains to carbamate insecticide chemicals appears to result from a fifth chromosomal gene which confers high activity of the microsome-NADPH enzyme system resulting in rapid detoxification of the insecticide. Synergists block the detoxification, inhibit the enzyme and decrease the magnitude of the resistance. This enzyme system also metabolizes many other types of insecticide chemicals; possibly it is a factor contributing to resistance to those compounds for which resistance is conferred by fifth chromosomal factor(s) involving oxidative detoxification mechanisms. Pyrethroids, certain organophosphates and a very few of the chlorinated hydrocarbons may also fall in this category.

3.2 Behaviour of Pesticides in the Environment

The widespread use and disposal of pesticides by farmers, institutions and the general public provide many possible sources of pesticides in the environment. Following release into the environment, pesticides may have many different fates. Pesticides which are sprayed can move through the air and may eventually end up in other parts of the environment, such as in soil or water. Pesticides which are applied directly to the soil may be washed off the soil into nearby bodies of surface water or may percolate through the soil to lower soil layers and groundwater. Pesticides which are injected into the soil may also be subject to the latter two fates. The application of pesticides directly to bodies of water for weed control, or indirectly as a result of leaching from boat paint, runoff from soil or other routes, may lead not only to build up of pesticides in water, but also may contribute to air levels through evaporation.

This incomplete list of possibilities suggests that the movement of pesticides in the environment is very complex with transfers occurring continually among different environmental compartments. In some cases, these exchanges occur not only between areas that are close together (such as a local pond receiving some of the herbicide application on adjacent land) but also may involve transportation of pesticides over long distances. The worldwide distribution of DDT and the presence of pesticides in bodies of water such as the Great Lakes far from their primary use areas are good examples of the vast potential of such movement.

While all of the above possibilities exist, this does not mean that all pesticides travel long distances or that all compounds are threats to groundwater. In order to understand which ones are of most concern, it is necessary to understand how pesticides move in the environment and what characteristics must be considered in evaluating contamination potential. Two things may happen to pesticides once they are released into the environment. They may be broken down, or degraded, by the action of sunlight, water or other chemicals, or microorganisms, such as bacteria. This degradation process usually leads to the formation of less harmful breakdown products but in some instances can produce more toxic products.

The second possibility is that the pesticide will be very resistant to degradation by any means and thus remain unchanged in the environment for long periods of time. The ones that are most rapidly broken down have the shortest time to move or to have adverse effects on people or other organisms. The ones which last the longest, the so-called persistent pesticides, can move over long distances and can build up in the environment leading to greater potential for adverse effects to occur.

3.2.1 Properties of Pesticides

In addition to resistance to degradation, there are a number of other properties of pesticides which determine their behavior and fate. One is how **volatile** they are; that is, how easily they evaporate. The ones that are most volatile have the greatest potential to go into the atmosphere and, if persistent, to move long distances. Another important property is **solubility in water**; or how easily they dissolve in water. If a pesticide is very soluble in water, it is more easily carried off with rainwater, as runoff or through the soil as a potential groundwater contaminant (leaching). In addition, the water-soluble pesticide is more likely to stay mixed in the surface water where it can have adverse effects on fish and other organisms. If the pesticide is very insoluble in water, it usually tends to stick to soil and also settle to the bottoms of bodies of surface water, making it less available to organisms.

3.2.2 Environmental Characteristics

From a knowledge of these and other characteristics, it is possible to predict in a general sense how a pesticide will behave. Unfortunately, more precise prediction is not possible because the environment itself is very complex. There are, for example, huge numbers of soil types varying in the amount of sand, organic matter, metal content, acidity, etc. All of these soil characteristics influence the behavior of a pesticide so that a pesticide which might be anticipated to contaminate groundwater in one soil may not do so in another.

Similarly, surface waters vary in their properties, such as acidity, depth, temperature, clarity (suspended soil particles or biological organisms), flow rate, and general chemistry. These properties and others can affect pesticide movement and fate. Everyone is familiar with the difficulties of forecasting weather, which is partly due to problems in predicting air flow patterns. As a result, determination of pesticide distribution in the atmosphere is subject to great uncertainty.

With such great complexity, scientists cannot determine exactly what will happen to a particular pesticide once it has entered the environment. However, they can divide pesticides into general categories with regard to, for example, persistence and potential for groundwater contamination and they can also provide some idea as to where the released pesticide will most likely be found at its highest levels. Thus, it is possible to gather information which can help make informed decisions about what pesticides to use in which situations and what possible risks are being faced due to a particular use.

3.2.3 Fate of Pesticide In The Atmosphere

Entry of Pesticides into the Atmosphere

Pesticides enter the atmosphere either by application drift, post-application vapour losses or wind erosion of pesticide treated soil. They and their photodegradation products may be transported long distances before the removal processes of atmospheric wet and dry deposition return them to the earth's surface

i. Application drift

Liquid sprays are applied through nozzles which provide metering, atomization, and uniform distribution of the pesticide mixture. The majority of atomizers use hydraulic pressure as the energy source for breaking the liquid into droplets. The proportion of the total spray volume contained in droplet sizes below 150μm can be used as an indicator of drift potential, because it is these small droplets that are most prone to movement under windy conditions.

ii. Post-application vapour losses

There are two types of applications. Pre-emergence applications, applied to the soil surface prior to the emergence of the crop, may be left undisturbed on the soil surface or incorporated by some form of soil disturbance into the upper layer of soil. Post-emergence applications are applied to the crop, a portion of which will penetrate the crop and deposit on the soil surface.

iii. Wind-erosion of pesticide-treated soil

Pesticides on the soil surface may be susceptible to transport through wind erosion of soil in which three processes are considered operative. Large soil particles can roll on the soil surface under the influence of wind and this movement is called surface creep. Smaller particles can become suspended in the air for short periods of time as they move laterally. Since all processes may involve soil particles with adsorbed pesticide, significant amounts of pesticide may be transported from the soil surface with the wind-eroded sediment.

In a study, overall losses for three winter wind erosion events for two soil incorporated herbicides, trifluralin and triallate, were approximately 1.5% of the amounts applied. Simultaneous losses of four postemergence herbicides (2,4-D, mecoprop, bromoxynil, diclofop) applied to the soil surface averaged 4.5%. This study demonstrate the potential for environmental transport of pesticides on wind-eroded sediment and its associated implications for off-site air and surface water quality.

3.2.4 Fate of Pesticide in the Aquatic System

The contamination of water bodies with pesticides can pose a significant threat to aquatic ecosystems and drinking water resources. Pesticides can enter water bodies via diffuse or via point sources. Diffuse-source pesticide inputs into water bodies are the inputs resulting from agricultural application on the field. These are tile drain outflow, baseflow seepage, surface and subsurface runoff and soil erosion from treated fields, spray drift at application, and deposition after volatilization. In contrast, point-source inputs derive from a localized situation and enter a water body at a specific or restricted number of locations. These are mainly farmyard runoff, sewage plants, sewer overflows, and accidental spills. There are also point sources of pesticides from non-agricultural use, e.g. from application on roads, railways or urban sealed surfaces such as parking lots.

Many factors, such as soil and pesticides properties, and crop management practices, govern the potential for groundwater or surface water contamination by pesticides.

3.2.4.1 Surface Water

Entry of pesticides into surface waters

Pesticides enter surface waters through run-off, wastewater discharges, atmospheric deposition and spills.

*i. **Atmospheric Deposition***

Once pesticides enter the atmosphere either by above mentioned pathway, they are subjected to transport over distances which can range to thousands of kilometres. At any point during transport, they are also subject to the removal processes of wet and dry deposition, both of which contaminate surface waters. In wet deposition, pesticides may be trapped in snow and hail or dissolved in rain. In dry deposition, pesticides sorbed to particles of wind-eroded soil.

ii. Surface Runoff

Surface waters include streams, rivers, lakes, reservoirs and oceans. Streams and reservoirs supply approximately 50% of the drinking water in the world. Surface waters receive a portion of their water from snow melt or rainfall runoff. Pesticides susceptible to surface runoff are those within the runoff-soil interaction zone or the top 0.5 to 1 cm of soil. Several factors may affect the amount of pesticide present within this zone. These include type of pesticide application, soil type, physiochemical properties and formulation type of the pesticide, field half-life of the pesticide, atmospheric deposition of pesticides

The pollution of aquatic system is depend on water solubility of pesticides. Water solubility describes the amount of pesticide that will dissolve in a known amount of water. It usually is measured in milligrams per liter of water or ppm and measures how easily a pesticide may be washed off the crop, leach into the soil or move with surface runoff.

3.2.4.2 Ground Water

Groundwater may be contaminated if pesticides leach from treated fields, mixing sites, washing sites, or waste disposal areas.

Entry of Pesticides Into Ground Waters

i. Surface runoff and erosion

Runoff is the movement of water over a sloping surface. It can carry pesticides dissolved in water and pesticides sorbed to eroding soil. The pesticides are either mixed in the water or bound to eroding soil. Runoff can also occur when water is added to a field faster than it can be absorbed into the soil. Pesticides may move with runoff as compounds dissolved in the water or attached to soil particles. The amount of pesticide runoff depends on slope, texture of the soil, soil moisture content, amount and timing of a rain event and type of pesticide used.

Soil erosion by water consists of two processes:
i) the detachment of soil particles from the soil surface, and
ii) their subsequent transport down slope.

Detachment is caused by raindrop impact and also by the abrasive power of surface runoff, especially when the runoff water flow has concentrated. Pesticides lost in runoff and erosion events leave the field either dissolved in runoff water or adsorbed to eroded soil particles. However, for most pesticides losses via runoff are considered far more important than losses via erosion, because the amount of eroded soil lost from a field is usually small compared with the runoff volume. Only for strongly sorbing substances with a K_{oc} greater than ca. 1000 L kg^{-1}, erosion is considered as the main loss pathway.

ii. Drainflow

The purpose of installing artificial subsurface drains is to prevent top soil saturation that otherwise would impair crop development, soil trafficability and workability. The main factors affecting pesticide inputs into surface waters via drainage are soil texture, site, drainage system, compound properties, weather, application rate and season.

iii. Leaching

Leaching is the movement of pesticides in water through the soil. Leaching occurs downward, upward, or sideways. The factors influencing whether pesticides will be leached into groundwater include characteristics of the soil and pesticide, and their interaction with water from a rain or irrigation.

Leaching can be increased when:
(I) the pesticide is water soluble,
(II) the soil is sandy,
(III) a rain-event occurs shortly after spraying, and
(IV) the pesticide is not strongly adsorbed to the soil.

Leaching of water and dissolved pesticides to depth in soil occurs by matrix flow and preferential flow. Matrix flow is the slower transport process in which the simultaneous movement of pesticides with water is determined by the physical-chemical properties of the pesticides. Such movement is dependent on its water solubility, vapour pressure, K_h and K_{oc}.

iv. Spray drift

Spray drift is the airborne movement of spray droplets away from a treatment site during application. Spray drift is affected by spray droplet size, wind speed and distance between nozzle and target. It can damage nearby sensitive crops or can contaminate crops ready to harvest and may be hazard to people, domestic animals, or pollinating insects. It can contaminate water in ponds, streams, ditches and harm aquatic plants and animals.

v. Point sources

Point-source inputs of pesticides consist of runoff from hard surfaces, mostly farmyards, storage facilities or roads. The contamination of hard surfaces arises from filling and cleaning of sprayers, improper handling of tank mix left overs, leaking of faulty equipment, incorrect storage of canisters. Of course accidental spills can occur due to leaking tanks on the road to the field to be treated.

3.2.5 Fate of Pesticide in the Plant-Soil System

Research in the fields of metabolism and the environmental behavior of pesticides has developed into interdisciplinary cooperation, in which pesticide chemists cooperate with agricultural chemists, soil scientists, microbiologists and plant physiologists. All the process which take place in the soil-plant system after the application of pesticides are of particular interest for agriculture. The ultraviolet fraction of sunlight is absorbed to a considerable extent by many chemical compounds, providing the energy necessary for photochemical reactions. Similar decomposition reactions take place during chemical and biochemical modifications in which microorganisims, plant roots and soil macrofauna are involved. Absorption and fixation processes have a influence on the availability of active substances in the soil for treated cultures and subsequent untreated crops.

3.2.5.1 Environmental Impact of Pesticides on Plants

Factors which influence leaf uptake and metabolism of pesticides are physicochemical behavior, formulation, droplet size and application technique, precipitation or rainfall and relative humidity, temperature, sunlight, plant species and physiological differences, e.g. stomata, upper/lower leaf surface, hairs, waxes, and time of application during the vegetative period. Similarly factors which influence root uptake and degradation of pesticides in soil are physicochemical behavior, application method and amount, physicochemical and biochemical reactions in the soil, climatic factors and plant development.

The degree of plant uptake is determined partially by the pesticide's water solubility. Plant uptake of pesticides prevents runoff or leaching.

- ***Volatilization from foliage***

Pesticides also may volatilize or be blown away by the wind. Volatilization from foliage is determined by the pesticide's vapor pressure, which is affected by temperature. The higher, the temperature, the greater the volatilization. Pesticides on foliage are most susceptible to volatilization after application, because over time, pesticides become incorporated into surface waxes. In general, pesticides with vapor pressure index values of less than 10 have a low potential to volatilize. Pesticides with vapor pressure index values greater than 1000 have a high potential to volatilize.

- ***Absorbtion***

Absorption is the uptake of pesticides and other chemicals into plants or microorganisms. Most pesticides break down once they are absorbed. Pesticide residues may be broken down or remain inside the plant or animal and be released back into the environment when the animal dies or as the plant decays. Some pesticides stay in the soil long enough to be absorbed by plants grown in a field years later.

3.2.5.2 Environmental Impact of Pesticides In Soil

- ***Adsorption***

Adsorption is the binding of pesticides to soil particles. The amount a pesticide is adsorbed to the soil varies with the type of pesticide, soil, moisture, soil pH, and soil texture. Pesticides are strongly adsorbed to soils that are high in clay or organic matter. Most soil-bound pesticides are less likely to give off vapours or leach through the soil. They are also less easily taken up by plants. For this reason you may require the higher rate listed on the pesticide label for soils high in clay or organic matter

- ***Sorption***

Sorption describes the attraction between a chemical and soil, vegetation, or other surfaces. However, sorption most often refers to the binding of a chemical to soil particles. Pesticides that are sorbed to soil particles are more likely to remain in the root zone where they may be available for plant uptake and microbial or chemical degradation.

Sorption is influenced by soil moisture, organic matter content, and texture. Pesticides are more readily sorbed onto dry soil because water competes with pesticides for binding sites in moist soil. Organic matter and clay particles both have plenty of surface area and are chemically active. Soils high in clay and organic matter, have a high potential to sorb pesticides. Clay content is also important for holding organic matter. Sand particles provide less surface area for sorption.

Generally, soil bound pesticides increase with time. This in turn corresponded with an increase in extractable residues. It means the more pesticide is binding to the soil organic matter, the more time after the application.

The sorption of a particular pesticide to a soil is measured in a laboratory by mixing water, pesticide, and soil. After equilibrium has been reached, the amount of pesticide remaining in solution is measured. The concentration of pesticide sorbed to the soil in the mixture is divided by the pesticide concentration still in solution. This yields the distribution coefficient, (K_d). K_d(L/kg) is the ratio of a chemical's sorbed concentration (mg/kg) to the dissolved concentration (mg/L). A low K_d indicates that more pesticide is in solution; a higher value indicates that the pesticide is more strongly sorbed to soil. The K_d determined in the laboratory will vary depending on the ratio of soil to water and the chemical properties of the pesticide and the soil. For this reason, the sorption coefficient (K_{oc}), is used to compare the relative sorption of pesticides. K_{oc} is the distribution coefficient (K_d) divided by the amount of organic carbon in the soil. The higher the K_{oc} value, the more strongly the pesticide is sorbed, and therefore, the less mobile it is. Higher K_{oc} (greater than 1000) indicate a pesticide that is very strongly attached to soil and is less likely to move unless soil erosion occurs. Lower values (≤ 300) indicate it tends to move with water and have the potential to leach or move with surface runoff.

- ***Degradation or breakdown processes***

Degradation is the process of pesticide breakdown after application. Pesticides are broken down by microbes, chemical reactions, and light or photodegradation. This process may take anywhere from hours or days to years, depending on environmental conditions and the chemical characteristics of the pesticide.

Microbial degradation is the breakdown of pesticides by microorganisms such as fungi, bacteria, and other soil microorganisms. Soil organic matter, texture, and site characteristics such as moisture, temperature, aeration, and pH-all affect microbial degradation. Microbial activity usually is greatest in warm, moist, well aerated soils with a neutral pH. Microbial breakdown tends to increase when: temperatures are warm soil pH is favourable, soil moisture and oxygen are adequate, soil fertility is good. Microbial degradation occurs at a higher rate in the surface soil horizons, particularly in areas with high organic matter. Usually, the rate decreases with depth in the soil, where conditions such as moisture, temperature, and aeration are less favorable for microbial activity.

Chemical degradation occurs when a pesticide reacts with water, oxygen, or other chemicals in the soil. As soil pH becomes extremely acidic or alkaline, microbial activity usually decreases. However, these conditions may favor rapid chemical degradation. Chemical breakdown is the breakdown of pesticides by chemical reactions in the soil. The rate and type of chemical reactions that occur are influenced by the binding of pesticides to the soil, soil temperatures, pH levels.

Photodegradation is the breakdown of pesticides by sunlight. All pesticides are susceptible to photodegradation to some degree. The intensity of sunlight, length of exposure, and properties of the pesticide affect the rate of photodegradation. Pesticides that are applied to foliage or to the soil surface are more susceptible to photodegradation than pesticides that are incorporated into the soil. Pesticides may break down faster inside plastic-covered greenhouses than inside glass greenhouses, since glass filters out much of the ultraviolet light that degrades pesticides.

- ***Volatilization from the soil***

Volatilization is the process of solids/liquids converting into a gas, which can move away from the initial application site. This movement is called vapour drift. Vapour drift from some herbicides can damage nearby crops. Volatilization from moist soil is determined by the moisture content of the soil, and by the pesticide's vapor pressure, sorption, and water solubility. Pesticides volatize most readily from sandy and wet soils. Hot, dry, or windy weather and small spray drops increase volatilization. Where recommended, incorporating the pesticide into the soil can help reduce volatilization. The rate of volatilization of pesticides from soil depends upon properties of the chemical and of the soil. On the other hand postapplication volatilization represents further significant pesticide input into the troposphere for several days/weeks after application.

The dominant factors that affect volatilization from soil and crops are vapor pressure, Henry's law constant (K_h, is defined as the concentration of pesticide in air divided by the concentration in water) and water solubility of pesticides, as well as its persistence in the soil or plant surface, and environmental conditions. K_h characterizes the tendency for a pesticide to move between the air and the "soil water." The higher the K_h, the more likely that a pesticide will volatilize from moist soil.

3.2.5.3 Movement of Pesticides in the Environment Via the Soil

- ***Erosion***

Erosion, soil particles which are transported by wind and water; pesticides attached to soil particles. WP formulations such as those used to apply atrazine and simazine in the present experiment appear to be susceptible to wind erosion when the soil is dry. Soil lost through wind.

erosion may transport herbicides to non-target areas. Incorporation may reduce herbicide concentrations at the soil surface, reducing loss on wind-erodible sediment.

There is potential hazard of environmental transport of herbicides in windblown sediment which may have implications for air and water quality. Wind erosion events affect air quality. If dust containing pesticides is inhaled, there may be an impact on human health. If the dust is deposited in waterways, then there may be a detrimental effect on water quality. Surface applied herbicides are adsorbed to soil particles in the very shallow surface layer which is the first to be removed by wind erosion. Hence the potential for removal of surface-applied chemicals by wind erosion is much higher than soil-incorporated pesticides. Incorporation increases herbicide efficacy. Therefore, potential transport of soil-incorporated herbicides by wind is much lower than that of surface-applied herbicides.

Wind erosion has detrimental effects on the economics of agriculture and the environment. During the dust storms, high amounts of radionuclides, heavy metals and residues of pesticides are transferred by the wind and contaminate the agrolandscapes. Research was conducted on the physical and chemical parameters of soils susceptible to wind erosion. Clay and microagregates <0.01 mm content are the main soil parameters influence the level of erodibility of soil by wind. Increase of clay and microagregates content leads to decrease of erodibility. There are many other problems caused by wind erosion which affect the environment. The behaviour of contaminants such as, remains of fertilizers and pesticides is different in various environments and perhaps depends on the binding of contaminants with soil particles. Some components of agrolandscape increase generation the dust during wind erosion and the dust then has an influence on neighbouring landscape contaminating the soils, water and other resources.

- ***Leaching***

Leaching is the downward movement of pesticides in the soil through cracks and pores. Soil normally filters water as it moves downward, removing contaminants such as pesticides. Soil and pesticide properties, geography and weather can influence the movement of pesticides (leaching). Pesticides that leach through soils may reach ground water.

Soil properties (organic matter, soil texture and soil acidity), pesticide properties (solubility, adsorption and persistence), pesticide application (rate of application and application method), and weather conditions are the factors of affecting leaching.

As a summary, the behaviour of pesticides in soils is governed by a variety of complex dynamic physical, chemical and biological processes, including sorption–desorption, volatilization, chemical and biological degradation, uptake by plants, run-off, and leaching. These processes directly control the transport of pesticides within the soil and their transfer from the soil to water, air or food. The relative importance of these processes varies with the chemical nature of the pesticides and the properties of the soil.

3.2.6 Role of Living Organisms

So far, the discussion has focused on air, soil and water. However, living organisms may also play a significant role in pesticide distribution. This is particularly important for pesticides which can accumulate in living creatures. An example of accumulation is the uptake of a very water-insoluble pesticide, such as chlordane, by a creature living in water. Since this pesticide is stored in the organism, the pesticide accumulates and levels increase over time. If this organism is eaten by a higher organism which also can store this pesticide, levels can reach higher values in the higher organism than is present in the water in which it lives. Levels in fish, for example, can be tens to hundreds of thousands of times greater than ambient water levels of the same pesticide. This type of accumulation is called bioaccumulation.

In this regard, it should be remembered that humans are at the top of the food chain and so may be exposed to these high levels when they eat food animals which have bioaccumulated pesticides and other organic chemicals. It is not only fish but also domestic farm animals which can be accumulators of pesticides and so care must be used in the use of pesticides in agricultural situations.

4.0 CONCLUSION

Two decades ago, the research on the metabolism of insecticide chemicals was pursued by only a few investigators; today, hundreds are involved. The information needed for each new pesticide chemical increases with the accumulating back-log of data and interpretations on previous compounds; fortunately, expertise in the approach to problems of this type is also increasing rapidly. Various pesticide chemical and drug-pesticide chemical interactions are now defined at the detoxication level, particularly those involving esterase or mixed-function oxidase enzymes; this area is one of increasing importance and concern.

5.0 SUMMARY

Organic insecticide chemicals metabolize in living organisms, the attack involving hydrolysis, hydroxylation, oxidation, reduction, dehalogenation, dehydrohalogenation, *O*-dealkylation, *N*-dealkylation and conjugation. The metabolic attack takes place at one or more sites on the molecule, and insects, plants and mammals frequently metabolize by the same general pathways.

Nicotine forms cotinine, rotenone suffers hydroxylation on a ring juncture and on the isopropenyl side chain, and pyrethroids degrade though oxidation of the trans-methyl group of the isobutenyl side chain. Methylenedioxyphenyl synergists hydroxylate at the methylene carbon of the heterocycic ring and suffer cleavage of the ether side chain(s). DDT and methoxychlor dehydrochlorinate in insects convert to acetic acid derivatives in mammals, and dechlorinate and hydroxylate at the trichloroethane moiety. Lindane rapidly converts to pentachlorocyclohexene. The chlorinated methano-bridged cyclohydrocarbons epoxidize and/or suffer hydroxylation, dechlorination and oxidation, bridged ketones sometimes being formed. The organophosphates and organophosphonates, and their thiono analogs hydrolyze at ester linkages and suffer hydroxylation, *N*-deallcylation, *O*-dealkylation, dehalogenation, dehydrohalogenation and/or hydrolysis, the thiono group being replaced by oxygen; reduction of the nitro group and oxidation of the thioether sulfur sometimes take place. Carbamates are surprisingly stable to hydrolysis, the main metabolic attack consisting of hydroxylation of the ring, or ring substituent, or of the *N*-methyl groups, and oxidation of thioether sulfur. Knowledge of the metabolic pathways involved is important to an understanding of the mechanisms of residue dissipation, selective toxicity, resistance, pesticide interactions and synergist action.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. What are the important advancements reckoned with in the study of insecticide metabolism?

2. State the importance of insecticides in metabolic studies

3. Draw a diagram of the pathways of metabolism of an insecticide chemical in living organisms

4. Describe the metabolic attack of nicotine insecticide by the mammalian liver

5. Discuss briefly the metabolism of the following insecticides;

a. DDT
b. Lindane
c. Organophosphates and Organophosphonates
d. Methyl- and dimethyl carbamates
e. Cyclodienes

6. Discuss the environmental and pesticide characteristics that affect the behaviour of pesticides in the environment

7. Explain the particular features or properties that affect the fate of pesticides in the following environmental media;

a. Atmosphere
b. Aquatic ecosystem
c. Plant-soil system
d. Living organisms

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UNIT 3 PROBLEMS OF RESISTANCE

CONTENTS

1.0 INTRODUCTION

Following the introduction of synthetic organic insecticides in the 1940's, such as DDT, it was not long before the first cases of resistance were detected and by 1947, resistance to DDT was confirmed in houseflies. Thereafter, with every new insecticide introduction, cyclodienes, organophosphates, carbamates, formamidines, pyrethroids, *Bacillus thuringiensis*, spinosyns and neonicotinoids, cases of resistance appeared some 2 to 20 years after their introduction in a number of key pest species. This phenomenon has been described as the 'pesticide treadmill', and the sequence is familiar. As a result of continued applications over time the pest evolves resistance to the insecticide and the resistant strain becomes increasingly difficult to control at the labeled rate and frequency. This in turn has often led to more frequent applications of the insecticide. The intensity of the resistance and the frequency of insecticide-resistant individuals in the population both increase still further and problems of control continue to worsen as yet more product is applied. Eventually users switch to another pesticide if one is available. The genetics of the heritable resistance traits and the intensive repeated application of pesticides, together are responsible for the rapid build-up of resistance in most insects and mites.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- define pesticide resistance
- explain the development of resistance
- give examples of pesticide resistance
- discuss the various mechanisms of resistance
- describe the management of resistance

3.0 MAIN CONTENT

3.1 Resistance: Definition and Development

Resistance may be defined as 'a heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to the label recommendation for that pest species'. Insecticide resistance can also be defined as a reduction in the sensitivity of an insect population to an insecticide. Cross-resistance occurs when resistance to one insecticide confers resistance to another insecticide, even where the insect has not been exposed to the latter product. Clearly, because pest insect populations are usually large in size and they breed quickly, there is always a risk that insecticide resistance may evolve, especially when insecticides are misused or over-used.

Natural selection by an insecticide allows some initially very rare, naturally occurring, pre-adapted insects with resistance genes to survive and pass the resistance trait on to their offspring. Through continued application of insecticides with the same MoA (Mode of Action), selection for the resistant individuals continues so the proportion of resistant insects in the population increases, while susceptible individuals are eliminated by the insecticide. Under permanent selection pressure, resistant insects outnumber susceptible ones and the insecticide is no longer effective. The speed with which resistance develops depends on several factors, including how fast the insects reproduce, the migration and host range of the pest, the availability of nearby susceptible populations, the persistence and specificity of the crop protection product, and the rate, timing and number of applications made. Resistance increases fastest in situations such as greenhouses, where insects or mites reproduce quickly, there is little or no immigration of susceptible individuals and the user may spray frequently.

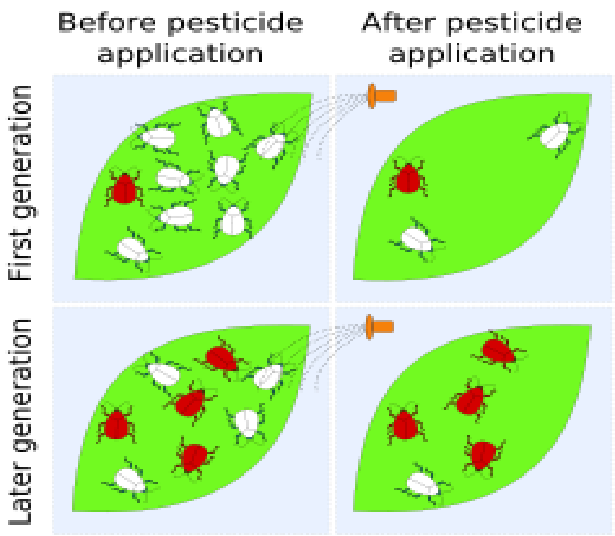

Fig. 7.1: Selection of Resistant Pests after Pesticide Application

Pesticide application can artificially select for resistant pests. In this diagram, the first generation happens to have an insect with a heightened resistance to a pesticide (red). After pesticide application, its descendants represent a larger proportion of the population because sensitive pests (white) have been selectively killed. After repeated applications, resistant pests may comprise the majority of the population.

3.2 Examples of Resistance

i. In the US, studies have shown that fruit flies that infest orange groves were becoming resistant to malathion, a pesticide used to kill them.

ii. In Hawaii and Japan, the diamondback moth developed a resistance to *Bacillus thuringiensis* about three years after it began to be used heavily.

iii. DDT is no longer effective in preventing malaria in some places, a fact which contributed to a resurgence of the disease.

iv. Colorado potato beetle has developed resistance to 52 different compounds belonging to all major insecticide classes. Resistance levels vary greatly among different populations and between beetle life stages, but in some cases can be very high (up to 2,000-fold).

3.3 Mechanism of Resistance

Resistance is reflected in repeated failure of an insecticide to achieve the expected level of control of insects when used according to the product label recommendations and where problems of product storage, application and unusual climatic or environmental conditions can be eliminated as causes of the failure. There are several ways insects can become resistant to crop protection products, and pests often exhibit more than one of these mechanisms at the same time.

a) Metabolic resistance

Resistant insects may detoxify or destroy the toxin faster than susceptible insects, or quickly rid their bodies of the toxic molecules. Metabolic resistance is the most common mechanism and often presents the greatest challenge. Insects use their internal enzyme systems to break down insecticides. Resistant strains may possess higher levels or more efficient forms of these enzymes. In addition to being more efficient, these enzyme systems also may have a broad spectrum of activity (i.e., they can degrade many different insecticides).

b) Target-site resistance

The target site where the insecticide acts in the insect may be genetically modified to prevent the insecticide binding or interacting at its site of action thereby reducing or eliminating the pesticidal effect of the insecticide.

c) Penetration resistance

Resistant insects may absorb the toxin more slowly than susceptible insects. Penetration resistance occurs when the insect’s outer cuticle develops barriers which can slow absorption of the chemicals into their bodies. This can protect insects from a wide range of insecticides. Penetration resistance is frequently present along with other forms of resistance, and reduced penetration intensifies the effects of those other mechanisms.

d) Behavioural resistance

Resistant insects may detect or recognize a danger and avoid the toxin. This mechanism of resistance has been reported for several classes of insecticides, including organochlorines, organophosphates, carbamates and pyrethroids. Insects may simply stop feeding if they come across certain insecticides, or leave the area where spraying occurred (for instance, they may move to the underside of a sprayed leaf, move deeper in the crop canopy or fly away from the target area).

3.4 Management of Resistance

The best strategy to avoid insecticide resistance is *prevention*. More and more pest management specialists recommend insecticide resistance management programs as one part of a larger integrated pest management (IPM) approach.

• **Monitor pests.** Scouting is one of the key activities in the implementation of an insecticide resistance management strategy. Monitor insect population development in fields (with the assistance of a crop consultant or advisor if necessary) to determine if and when control measures are warranted. Monitor and consider natural enemies when making control decisions. After treatment, continue monitoring to assess pest populations and their control.

• **Focus on economic thresholds.** Insecticides should be used only if insects are numerous enough to cause economic losses that exceed the cost of the insecticide plus application. An exception would be in-furrow, at-planting treatments for early season pests that usually reach damaging levels each year. Consult local crop advisors about economic thresholds for target pests in your area.

• **Take an integrated approach to managing pests.** Use as many different control measures as possible. Effective IPM based programs will include the use of synthetic insecticides, biological insecticides, beneficial arthropods (predators and parasites), cultural practices, transgenic plant varieties, crop rotation, pest-resistant crop varieties and chemical attractants or deterrents. Select insecticides with care and consider the impact on future pest populations and the environment. Avoid broad-spectrum insecticides when a narrow-spectrum or more specific insecticide will work.

• **Time applications correctly.** Apply insecticides when the pests are most vulnerable. For many insects this may be when they have just emerged. Use application rates and intervals recommended by the manufacturer or a local pest management expert (i.e., university insect management specialist, county Extension agent, or crop consultant).

• **Mix and apply carefully.** As the potential for resistance increases, the accuracy of insecticide applications in terms of dose, timing, coverage, etc. assumes greater importance. The pH of water used to dilute some insecticides in tank mixes may need to be adjusted to the product manufacturer's specifications. In aerial application, the swath widths should be marked, preferably by permanent markers. Sprayer nozzles should be checked for blockage and wear, and should be able to handle pressure adequate for good coverage. Spray equipment should be properly calibrated and checked on a regular basis. In tree fruits, proper and intense pruning will allow better canopy penetration and tree coverage. Use application volumes and techniques recommended by the manufacturers and local crop advisors.

• **Alternate different insecticide classes.** Avoid the repeated use of the same insecticide or insecticides in the same chemical class, which can lead to resistance and/or cross-resistance. Rotate insecticides across all available classes to slow resistance development. In addition, do not tank-mix products from the same insecticide class. Rotate insecticide classes and modes of action, consider the impact of pesticides on beneficial insects, and use products at labeled rates and spray intervals.

A key element of effective resistance management is the use of alternations, rotations, or sequences of different insecticide MoA classes. Users should avoid selecting for resistance or cross-resistance by repeated use within the crop cycle, or year after year, of the same insecticide or related products in the same MoA class.

Fig. 7.2: Representation of a Sequence of Insecticides through a Season

• **Protect beneficial arthropods.** Select insecticides in a manner that is the least damaging to populations of beneficial arthropods. For example, applying insecticides in-furrow at planting or in a band over the row rather than broadcasting will help maintain certain natural enemies.

• **Preserve susceptible genes.** Preserve susceptible individuals within the target population by providing a haven for susceptible insects, such as unsprayed areas within treated fields, adjacent "refuge" fields, or habitat attractions within a treated field that facilitate immigration. These susceptible individuals may outcompete and interbreed with resistant individuals, diluting the resistant genes and therefore the impact of resistance.

• **Consider crop residue options.** Destroying crop residue can deprive insects of food and overwintering sites. This cultural practice will kill insecticide-resistant pests (as well as susceptible ones) and prevent them from producing resistant offspring for the next season. However, review your soil conservation requirements before removing crop residue.

4.0 CONCLUSION

The problems of resistance is one that is common in pest management. This unit emphasized the various examples of resistance, the different mechanisms and their explanations, and ways to manage resistance. The best strategy being proffered is prevention.

5.0 SUMMARY

Resistance may be defined as a reduction in the sensitivity of an insect population to an insecticide. Examples of resistance include; the resistance of fruit flies that infest orange groves in the US to malathion, resistance of the female anopheles mosquito to DDT hence making it no longer effective in preventing malaria, etc. The mechanisms of resistance are; metabolic resistance, target-site resistance, penetration resistance and behavioural resistance. Finally, in the management of resistance, the best strategy is prevention. Some of these strategies include; monitoring pests, focus on economic thresholds, timing applications correctly, alternating different insecticide classes, considering crop residue options, preserving susceptible genes, amongst others.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. What is the term Resistance?

2. Describe a scenario of resistance of a pest to pesticide application(s)

3. Give examples of resistance

4. Explain four mechanisms of resistance that you know

5. In pest management, what is the best strategy to utilize in the management or control of resistance

6. Discuss succinctly the various means of managing resistance

7.0 FURTHER READING / REFERENCES

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UNIT 4 INTEGRATED PEST MANAGEMENT

CONTENTS

1.0 INTRODUCTION

Integrated pest management is a combination of various approaches to the management of pests. The need for this came about because the use of a singular approach usually doesn't eliminate or bring the pests to a considerable manageable level.

This unit treats all aspect of integrated pest management i.e. the principles, process, tools/components as well as stages in crop protection leading to IPM. Explanation of each point is succinctly discussed in this unit.

2.0 OBJECTIVES

At the end of this unit, you should be able to:

- Define integrated pest management
- State the reasons for pest management
- Describe the stages in crop protection leading to IPM
- Discuss the principles behind IPM
- Explain the process of IPM
- Draw a chart showing how the various tools or components of IPM interact

3.0 MAIN CONTENT

3.1 IPM Definition

IPM definition by FAO (1967)

Integrated Pest Management (IPM) is a system that, in the context of associated environment and population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains pest populations at levels below those causing economic injury.

IPM definition by Luckmann and Metcalf (1994)

IPM is defined as the intelligent selection and use of pest control tactics that will ensure favourable economical, ecological and sociological consequences.

In IPM, one attempts to prevent infestation, to observe patterns of infestation when they occur, and to intervene (without poisons) when one deems necessary.

3.2 History of Integrated Pest Management

- Michelbacher and Bacon (1952) coined the term "integrated control"

- Stern, *et al*. (1959) defined integrated control as "applied pest control which combines and integrates biological and chemical control"

- Geier (1966) coined the term "pest management"

- Council on Environmental Quality (CEQ, 1972) gave the term “Integrated Pest Management”

- Food and Agricultural Organization (FAO, 1967) defined IPM as “a pest management system, that, in the context of associated environment and population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains pest populations at levels below those causing economic injury”

- In 1989, IPM Task Force was established and in 1990. IPM Working Group (IPMWG) was constituted to strengthen implementation of IPM at international level.

- In 1997, Smith and Adkisson were awarded the World Food Prize for pioneering work on implementation of IPM.

3.3 Need for Pest Management (or) Why Pest Management

1. Development of resistance in insects against insecticides e.g. OP and synthetic pyrethroid resistance in *Helicoverpa armigera*.

2. Out break of secondary pests e.g. Whiteflies emerged as major pest when spraying insecticide against *H. armigera*.

3. Resurgence of target pests e.g. BPH of rice increased when some OP chemicals are applied.

4. When number of application increases, profit decreases.

5. Environmental contamination and reduction in its quality.

6. Killing of non-target animals and natural enemies.

7. Human and animal health hazards.

3.4 Stages in Crop Protection leading to IPM

1.	Subsistence phase	Only natural control, no insecticide use
2.	Exploitation phase	Applying more pesticides, growing HY varieties and get more yield and returns
3.	Crisis phase	Due over use pesticides, problem of resurgence, resistance, secondary pest out break, increase in production cost
4.	Disaster phase	Due to increased pesticide use - No profit, high residue in soil - Collapse of control system
5.	Integrated Management Phase	IPM integrates ecofriendly methods to optimize control rather than maximise it.

3.5 Principles of Integrated Pest Management

An IPM system is designed around six basic components:

1. **Acceptable pest levels**

The emphasis is on *control*, not *eradication*. IPM holds that wiping out an entire pest population is often impossible, and the attempt can be expensive and environmentally unsafe. IPM programmes first work to establish acceptable pest levels, called action thresholds, and apply controls if those thresholds are crossed. These thresholds are pest and site specific, meaning that it may be acceptable at one site to have a weed such as white clover, but at another site it may not be acceptable. By allowing a pest population to survive at a reasonable threshold, selection pressure is reduced. This stops the pest gaining resistance to chemicals produced by the plant or applied to the crops. If many of the pests are killed then any that have resistance to the chemical will form the genetic basis of the future, more resistant, population. By not killing all the pests there are some un-resistant pests left that will dilute any resistant genes that appear.

2. **Preventive cultural practices**

Selecting varieties best for local growing conditions, and maintaining healthy crops, is the first line of defense, together with plant quarantine and 'cultural techniques' such as crop sanitation (*e.g.* removal of diseased plants to prevent spread of infection).

3. **Monitoring**

Regular observation is the cornerstone of IPM. Observation is broken into two steps, first; inspection and second; identification. Visual inspection, insect and spore traps, and other measurement methods and monitoring tools are used to monitor pest levels. Accurate pest identification is critical to a successful IPM program. Record-keeping is essential, as is a thorough knowledge of the behavior and reproductive cycles of target pests. Since insects are cold-blooded, their physical development is dependent on the temperature of their environment. Many insects have had their development cycles modeled in terms of degree days. Monitor the degree days of an environment to determine when is the optimal time for a specific insect's outbreak.

4. **Mechanical controls**

Should a pest reach an unacceptable level, mechanical methods are the first options to consider. They include simple hand-picking, erecting insect barriers, using traps, vacuuming, and tillage to disrupt breeding.

5. **Biological controls**

Natural biological processes and materials can provide control, with minimal environmental impact, and often at low cost. The main focus here is on promoting beneficial insects that eat target pests. Biological insecticides, derived from naturally occurring microorganisms (*e.g.*: *Bt*, entomopathogenic fungi and entomopathogenic nematodes), also fit in this category.

6. **Responsible Pesticide Use**

Synthetic pesticides are generally only used as required and often only at specific times in a pests life cycle. Many of the newer pesticide groups are derived from plants or naturally occurring substances (*e.g.*: nicotine, pyrethrum and insect juvenile hormone analogues), but the toxophore or active component may be altered to provide increased biological activity or stability. Further 'biology-based' or 'ecological' techniques are under evaluation.

An IPM regime can be quite simple or sophisticated. Historically, the main focus of IPM programmes was on agricultural insect pests. Although originally developed for agricultural pest management, IPM programmes are now developed to encompass diseases, weeds, and other pests that interfere with the management objectives of sites such as residential and commercial structures, lawn and turf areas, and home and community gardens.

3.6 Process of Integrated Pest Management

IPM is applicable to all types of agriculture and sites such as residential and commercial structures, lawn and turf areas, and home and community gardens. Reliance on knowledge, experience, observation, and integration of multiple techniques makes IPM a perfect fit for organic farming (sans artificial pesticide application). For large-scale, chemical-based farms, IPM can reduce human and environmental exposure to hazardous chemicals, and potentially lower overall costs of pesticide application material and labor.

1. **Proper identification of pest - What is it?**

Cases of mistaken identity may result in ineffective actions. If plant damage due to over-watering are mistaken for fungal infection, spray costs can be incurred, and the plant is no better off.

2. **Learn pest and host life cycle and biology**.

At the time you see a pest, it may be too late to do much about it except maybe spray with a pesticide. Often, there is another stage of the life cycle that is susceptible to preventative actions. For example, weeds reproducing from last year's seed can be prevented with mulches. Also, learning what a pest needs to survive allows you to remove these.

3. Monitor or sample environment for pest population - How many are here?

Preventative actions must be taken at the correct time if they are to be effective. For this reason, once the pest is correctly identified, monitoring must begin *before* it becomes a problem. For example, in school cafeterias where roaches may be expected to appear, sticky traps are set out before school starts. Traps are checked at regular intervals so populations can be monitored and controlled before they get out of hand. Some factors to consider and monitor include: Is the pest present/absent? What is the distribution - all over or only in certain spots? Is the pest population increasing, decreasing or remaining constant?

4. Establish action threshold (economic, health or aesthetic) - How many are too many?

In some cases, a certain number of pests can be tolerated. Soybeans are quite tolerant of defoliation, so if there are a few caterpillars in the field and their population is not increasing dramatically, there is not necessarily any action necessary. Conversely, there is a point at which action *must* be taken to control cost. For the farmer, that point is the one at which the cost of damage by the pest is *more* than the cost of control. This is an economic threshold. Tolerance of pests varies also by whether or not they are a health hazard (low tolerance) or merely a cosmetic damage (high tolerance in a non-commercial situation).

Different sites may also have varying requirements based on specific areas. White clover may be perfectly acceptable on the sides of a tee box on a golf course, but unacceptable in the fairway where it could cause confusion in the field of play.

5. Choose an appropriate combination of management tactics

For any pest situation, there will be several options to consider. Options include, mechanical or physical control, cultural controls, biological controls and chemical controls. Mechanical or physical controls include picking pests off plants, or using netting or other material to exclude pests such as birds from grapes or rodents from structures. Cultural controls include keeping an area free of conducive conditions by removing or storing waste properly, removing diseased areas of plants properly. Biological controls can be support either through conservation of natural predators or augmentation of natural predators.

Augmentative control includes the introduction of naturally occurring predators at either an inundative or inoculative level. An inundative release would be one that seeks to inundate a site with a pest's predator to impact the pest population. An inoculative release would be a smaller number of pest predators to supplement the natural population and provide ongoing control. Chemical controls would include horticultural oils or the application of pesticides such as insecticides and herbicides. A Green Pest Management IPM program would use pesticides derived from plants, such as botanicals, or other naturally occurring materials.

6. Evaluate results - How did it work?

Evaluation is often one of the most important steps. This is the process to review an IPM program and the results it generated. Asking the following questions is useful: Did actions have the desired effect? Was the pest prevented or managed to farmer satisfaction? Was the method itself satisfactory? Were there any unintended side effects? What can be done in the future for this pest situation? Understanding the effectiveness of the IPM program allows the site manager to make modifications to the IPM plan prior to pests reaching the action threshold and requiring action again.

3.7 Tools or Components of Integrated Pest Management

(Arranged in increasing order of complexity)

i. Cultural method or use of agronomic practices:

1. Crop rotation
2. Crop refuse destruction
3. Tillage of soil
4. Variation in time of planting or harvesting
5. Pruning or thinning
6. Fertilizer management
7. Water management
8. Intercropping
9. Trap crop

ii. Host plant resistance - Antixenosis, antibiosis, tolerance

iii. Mechanical methods of pest control

1. Hand destruction
2. Exclusion by screens, barriers
3. Trapping, suction devices, collecting machine
4. Crushing and grinding

iv. Physical methods

1. Heat
2. Cold
3. Energy - light trap, irradiation, light regulation
4. Sound

v. Biological methods

1. Protection and encouragement of NE
2. Introduction, artificial increase and colonizing specific parasitoids and predators
3. Pathogens on insects like virus, bacteria, fungi and protozoa
4. Use of botanicals like neem, pongam, etc.

vi. Chemical methods

1. Attractants
2. Repellents
3. Insecticides - OC, OP, carbamates, pyrethroids, etc.
4. Insect growth inhibitors
5. Chemosterilants

vii. Behavioural methods

1. Pheromones
2. Allelochemics

viii. Genetic/biotechnology method

- Release of genetically incompatible/sterile pests
- Transgenic plant

ix. Regulatory/legal method

- Plant/animal quarantine
- Eradication and suppression programme

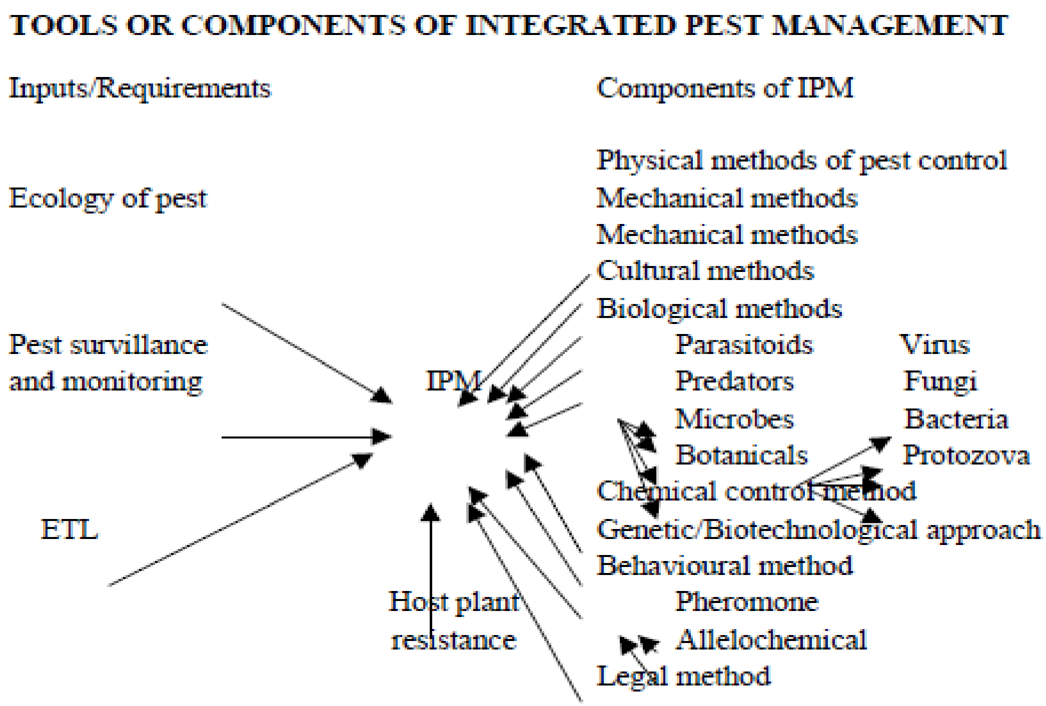

Fig. 8.1: Chart showing relationship between tools or components of IPM

4.0 CONCLUSION

In this unit, you have studied the meaning of integrated pest management, how IPM came about, the reasons why we need IPM, the basic components of pest management and the process of IPM.

5.0 SUMMARY

IPM may be defined as the intelligent selection and use of pest control tactics that will ensure favourable economical, ecological and sociological consequences. IPM is necessary for the following reasons; outbreak of secondary pests, development of resistance in insects against insecticides, resurgence of target pests, killing of non-target animals and natural enemies amongst others. An IPM is designed around six basic components viz; acceptable pest levels, preventive cultural practices, monitoring, mechanical controls, biological controls and responsible pesticide use. The processes involved in IPM include; proper identification of the pest, knowledge of pest and host life cycle and biology, establishing action thresholds (economic, health or aesthetic), choosing an appropriate combination of management tactics amongst others.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. Define the term Integrated Pest Management
2. Describe the history of IPM
3. Why do we need integrated pest management programmes
4. Explain the principles of IPM
5. What are the processes involved in IPM
6. Discuss the tools of IPM

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MODULE 3

UNIT 1 ALTERNATIVE CONTROL STRATEGIES: INSECT-PLANT CO-EVOLUTION

CONTENTS

1.0 INTRODUCTION

In this unit, the various types and aspects of insect – plant co-evolution will be discussed.

2.0 OBJECTIVES

At the end of this unit, you should be able to;

- explain the meaning of insect-plant co-evolution
- Discuss the types of insect-plant coevolution with examples
- describe the insect aspect
- elucidate the plant aspect
- expound the various plant-insect interactions

3.0 MAIN CONTENT

3.1 Meaning and Development of Insect-Plant Co-evolution

Evolution of land plants (especially flowering plants) is a major force driving the diversity of insects. As diversity of land plants has increased, the diversity of insects has increased. Interaction between plants and insects is an example of co-evolution.

Coevolution can occur between:

- a single plant and a single insect, or
- between a single plant and a group of insects, or
- between a group of insects and a group of closely-related plants

This can occur in one of two ways, depending on whether the interaction is beneficial to both parties (mutualism) or is beneficial to one but harmful to another (predation)

3.2 Types of Insect – Plant Co-evolution

3.2.1 Mutualistic Co-evolution

In this type of coevolution, the two parties change (evolve) in such a way to enhance the effectiveness of the interaction. This type of coevolution is common in interactions between plants and their insect pollinators, as well as some other specialized cases. If the coevolution is "extreme" enough, the two partners may become completely dependent on each other (called an obligate mutualism)

Fig. 9.1: The Darwin hawk moth, *Xanthopan morganii* and the star orchid, *Angraecum sesquipedale*, both from Madagascar. This moth is the only pollinator of this orchid.

Example of Obligate Mutualism: Ants and *Acacia*

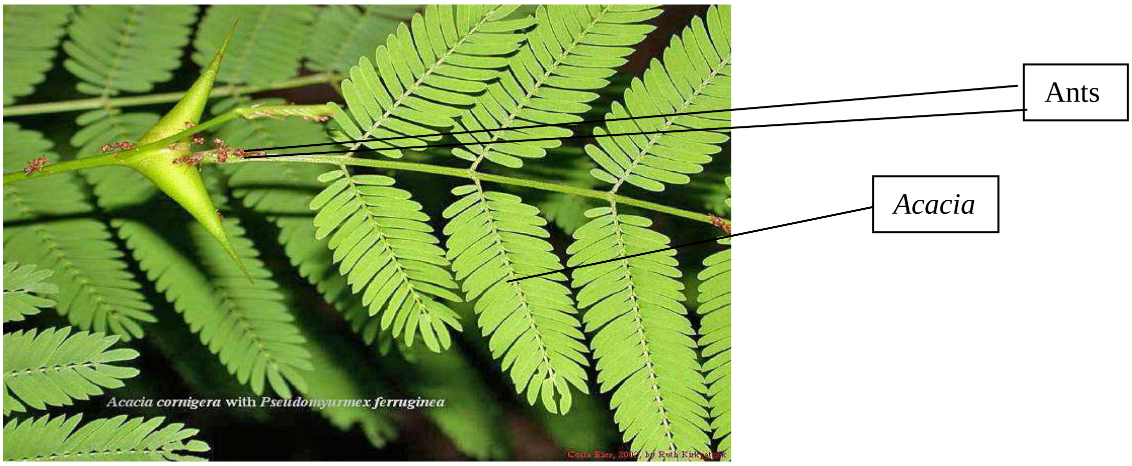

Fig. 9.2: Ants and *Acacia*: Many species of plants in the genus *Acacia* have mutualistic ants of the genus *Pseudomyrmex* associated with them

<u>Benefits of Mutualism</u>

Benefits to *Acacia;*

- Ants prevent herbivores from feeding on plant by killing them or chasing them off
- Ants remove any other plants growing nearby or on “their” Acacia (which decreases competition)

Benefits to *Pseudomyrmex* ants;

- A safe home (ants live in the trunk, and enter by chewing through the large hollow thorns)
- Plant provides two food sources;
    - Extrafloral nectaries which provide nectar
    - Beltian bodies which are high in protein

<u>Effects of Mutualism</u>

Dan Janzen, in 1966, examined effects of ant removal on *Acacia*. When ants were removed and kept off plants…

- The number of herbivorous insects increased dramatically
- The growth rate decreased dramatically
- Survival of plants over the course of a year declined dramatically

Thus, although removal of ants did not immediately kill *Acacia*, they did not grow well and none reproduced…and so *Acacia* need ants! Note that ants also need *Acacia*, since they are never found elsewhere unless looking for a new *Acacia*.

3.2.2 "Arms Race" Co-evolution

In this type of coevolution, one party (usually the plant) evolves so as to reduce or eliminate the "attacks" of the other party (usually the insect). The second party must then counteract these changes in the first party, so that it can more effectively attack it. This type of coevolution is common between plants and their insect predators

<u>A possible example of "arms race" coevolution</u>

Milkweeds (in the genus *Asclepias*) are fed upon by insects. Some individuals develop foul-tasting and toxic chemicals (cardenolide glycosides) which deter plant feeders. In turn, some insects develop ability to detoxify these chemicals, either getting rid of them or storing them in their bodies

3.3 The Insect Aspect

The insect aspect of the insect/plant interactions is often described as a series of steps, in time and space that lead to suitability of a plant for the insect. The major steps usually recognized by authorities include:

1. *Finding the general habitat*: Insects locate the general area of the host by means usually related to the plant. Physical stimuli such as light, wind, gravity and perhaps temperature and humidity may help orient dispersing insects to the overall location of the host. This step is most important when a species does not reside in an area year-round as with many migrating forms.

2. *Finding the host plant*: Once in the general area, the insect must find a proper host. Most insects rely on vision and/or smell to locate a host plant. Remote factors in

locating the plant include colour, size and shape. Much of the information on colour in host finding is limited mainly to aphids (Homoptera: Aphididae) and whiteflies (Homoptera: Aleyrodidae), which are attracted to yellow surface. Colour usually cannot be used in plant resistance because changing it affects fundamental physiological processes. In a few instances, however, red cultivars of cotton, cabbage and oats have been shown less attractive to insects and yet they have retained good agronomic characteristics. In addition to colour, some insects, like fruit flies, Ragoletics species, are known to associate shape and size of trees in locating hosts.

Once insects are in contact with the plant, short-range stimuli arrest further movement. These stimuli are both physical, exciting tactile receptors and chemical exciting chemoreceptors on tarsi, antennae and mouthparts.

3. *Accepting the plant as a proper host*: subsequent to host finding, insects may take test bites as do some caterpillars to confirm host recognition. Continuous feeding is seemingly governed by the stimulation from various chemicals. In a monophagus insect, the silkworm (*Bombyx mori*), a series of substances are perceived in mulberry leaves that seem to mediate biting, swallowing and continued feeding. Feeding to satiation then follows in the presence of appropriate chemicals.

   Major physical factors involved in acceptance of a host may include leaf and stem toughness, leaf surface waxes and pubescence (density and type of hairs). These factors may be important in relation to feeding and/or oviposition.

4. *Sufficiency of the plant for survival and successful reproduction of the insect population*: Sufficiency of the plant as a host is finally determined during feeding. If nutrients are adequate and no toxicity occurs, the insect completes development within a normal time period and becomes an adult. Also, sufficiency is indicated in normal adult longevity and fecundity (the production of male and female gametes).

3.4 The Plant Aspect

As the supplier of physical and chemical stimuli, the plant itself becomes an important participant in the insect and host-plant relationship. Both morphological and physiological characteristics of a plant elicit given insect responses.

1. *Morphological characteristics*: Plant morphological features may produce physical stimuli or bar insect activity. Variations in foliage size, shape, colour and presence or absence of glandular secretions may determine degree of acceptance or utilization by insects. Pubescence and tissue toughness sometimes limit insect mobility and feeding.

2. *Physiological characteristics*: These characteristics influencing insects usually involve chemicals that are the products of plant metabolism. Such chemicals are the result of primary and secondary metabolic processes.

3.5 Plant-Insect Interaction I: Feeding

Earliest terrestrial insects likely were scavengers (or predators after insects became established on land). They may have initially used plants by feeding directly on leaves, roots, spores or pollen. Plant feeding really took off when flowering plants arose, about 125 million years ago

3.5.1 Some Definitions

Feeding on plants is called either herbivory or phytophagy. Insects eating plants are referred to as phytophagous species. Phytophagous insects may be…

- Monophagous, meaning they eat only one kind of plant (perhaps even only one species);
- Oligophagous, meaning they feed on several different kinds (or species) of plants; or
- Polyphagous, meaning they feed on a wide variety of plants

3.5.2 Categories of Phytophagous Insects;

- Leaf Chewers
- Plant miners & plant borers
- Sap suckers
- Seed predators
- Nectar or pollen feeders

- Gall formers

3.5.2.1 Leaf Chewers

They eat entire leaves or large portions of leaves. Primary groups are: lepidopteran larvae (caterpillars), coleopterans (both adults and larvae), and orthopterans (both adults and nymphs). Also sawflies and walking sticks. A typical estimate of damage is 5-20% of total leaf area per plant. Leaf-chewers can cause lots of economic damage.

Fig. 9.3: Adult Japanese Beetles

Fig. 9.4: Larval Alfalfa weevil

Fig. 9.5: Leaf skeleton after attack by the gum leaf skeltoniser (a caterpillar)

What affects leaf damage?

- Toughness of the leaf (difficulty to chew)
- Water and/or nutrient content of leaf
- Levels of secondary compounds (toxins, alkaloids, etc.)

- Physical characteristics of the leaf or plant (thorns, hairs, wax, etc.)
- Age or stage of the insect;
    - Sometimes only larva or only adult eats the leaf
    - Sometimes types of leaf or amount of damage varies (increases usually) with age

3.5.2.2 Plant Miners

Mining involves burrowing into leafs or (less frequently) just below the surface of stems, fruits or roots. Typically leaves a narrow trail or patch (especially in leaves), often filled with frass. It is done primarily by larvae of dipterans and lepidopterans; less frequently by larvae of coleopterans and hymenopterans. They cause economic damage by affecting health and/or appearance of plant.

Fig. 9.6: A Leaf-mining Fly

Fig. 9.7: Locust leaf miner beetle

3.5.2.3 Plant Borers

Boring involves burrowing more deeply into stems, roots, or fruits. It is always done by larvae. Borers may feed on living or dead tissue.

- Stalk borers include sawflies and some lepidopterans
- Wood borers include coleopterans, lepidopterans, and hymenopterans
- Root borers include coleopterans and lepidopterans
- Fruit borers include dipterans, coleopterans, and lepidopterans

Fig. 9.8: A Soybean stem borer larva
(a ceramycid beetle)

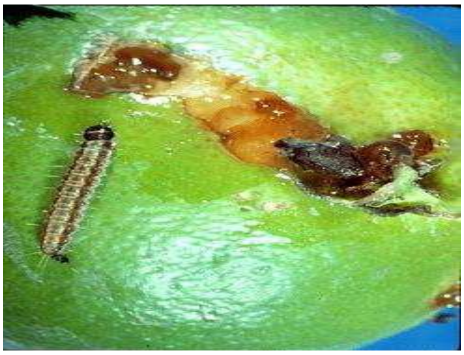

Fig. 9.9 : An orange fruit borer
(a moth larva)

3.5.2.4 Sap Suckers

They pierce plant tissue to obtain liquid from either phloem (most commonly) or Xylem. They stick stylets into a vein, or midrib, or parenchyma of leaf or smaller stems. They may have enzymes in saliva that assists in digesting plant cells. Vast majority are hemipterans, but a few thysanopterans (thrips) do this as well.

Fig. 9.10: A Winged Aphid feeding on a wheat leaf

3.5.2.5 Seed Eaters

Some eat the entire seed, but many feed on the inside of the seed (by boring into it). Done by harvester ants, some coleopterans and hemipterans, and a few lepidopterans. Some seeds have special structures called elaiosomes which are edible; ants will carry seeds to a nest and eat this, thus dispersing the seed

Fig. 9.11: The seed beetle, *C. maculatus*

Fig. 9.12: Ant carrying seed with elaisomes

3.5.2.6 Nectar or Pollen Eaters

Nectar is high in sugars (carbohydrates) but low in proteins, while pollen is high in proteins but low in carbs. Nectar feeders generally have highly modified haustellate mouthparts. Includes many hymenopterans, lepidopterans, coleopterans, dipterans, and thysanopterans

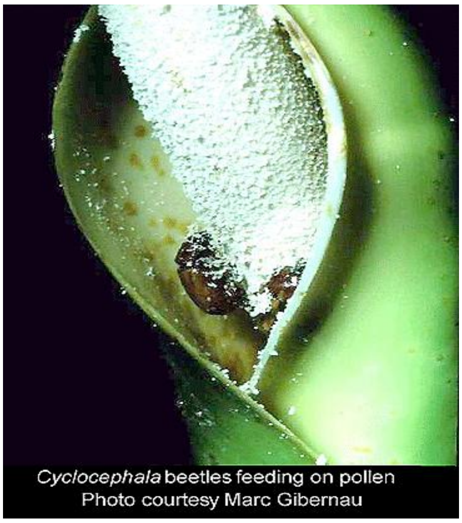

Fig. 9.13: Nectar-feeding Bee

Fig. 9.14: *Cyclocephala* beetles feeding on pollen of an aroid (such as *Philodendron*)

3.5.2.7 Gall Formers

Galls are an abnormal or pathological growth in plants, done as a response to some invader (such as a feeding insect, a virus, a bacteria, a fungus, etc.). Galls may form via the plant increasing the rate at which new cells form, or by increasing the number of cells produced, or by increasing the size of cells that it makes. Nearly all insect-associated galls are made in response to larval hemipterans, dipterans, or hymenopterans. Some thysanopterans, coleopterans, and lepidopterans also cause gall formation. Adults may also live inside galls.

Gall Appearance

Galls may be simple in shape or complex, with distinct tissue layers. They may be indeterminate (final shape not pre-determined) or determinate (final shape is always the same). Some galls have openings to the outside called ostioles

Fig. 9.15: Oak leaf gall from the cynipid wasp, *Antron douglasii*

Fig. 9.16: Galls on a grape leaf

Initiation of a Gall

Initiation may be controlled by either plant or insect, but increasing evidence supports idea that insect exhibits more control. That is, insect wants plant to make a gall. Oftentimes, gall formation ceases if the larva dies. Initiation may be affected by:

- Feeding action (piercing or chewing of tissue)
- Oral secretion
- Secretions from other glands (anal glands, accessory glands)

Transmission of genetic material to the plant, either from viruses or viroids.

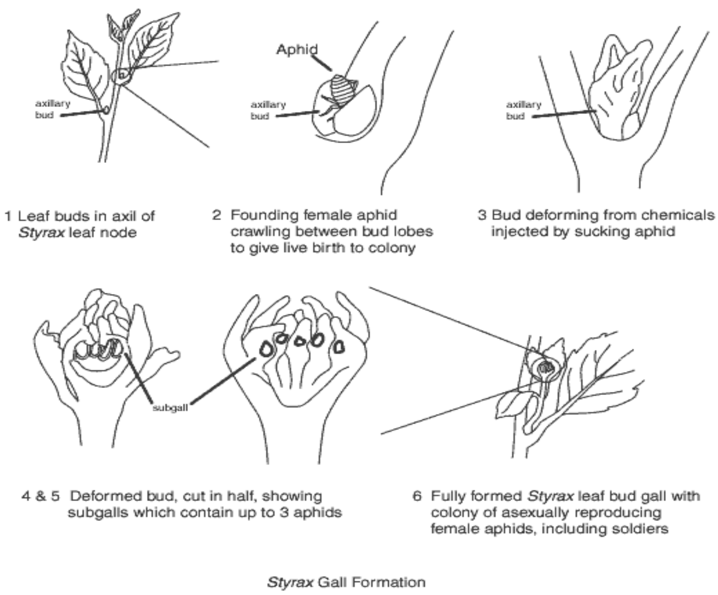

Fig. 9.17: Gall Formation in a named Plant

Galls may have evolved from either mining/boring or surface feeding. The gall itself is beneficial to the insect, but probably not to the plant. It acts as shelter and probably increased food availability. However, galls are also obvious and so may attract predators, parasitoids or "squatters" (inquilines)

3.5.3 Induced Defenses

Many plants will release chemicals upon being attacked by phytophagous insects. These chemicals can signal predators of the herbivore, and attract them to attack it Or, these chemicals can signal other plants to produce chemicals to deter the herbivores.

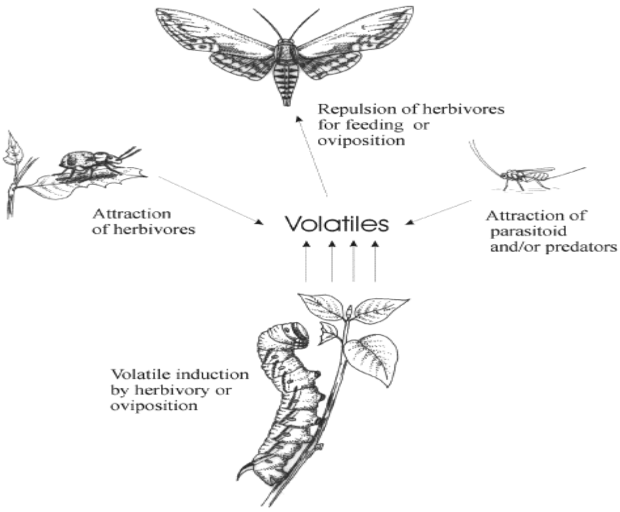

Fig. 1. Trophic interactions among host plants, herbivores, and predators or parasitoids mediated by plant volatiles.

Fig. 9.18: An example of Induced Defenses initiated by Volatiles (Chemicals) from the Plant

3.6 Plant-Insect Interaction II: Pollination

Pollination is beneficial to both the insect and the plant. Insect gets food (nectar or pollen), Plant increases probability of successful reproduction. Flowers have evolved as an indicator of food (a reward) to their pollinators. Flower anatomy ensures that, while feeding, the pollinator also picks up pollen. Pollen is then transported to another flower, where some will be transferred to the stigma of the female reproductive structure.

3.6.1 Variation in flowers

Individual flowers can be…

- Males only
- Females only
- Both male and female

Individual plants can…

- have flowers of one sex only
- have both distinct male and distinct female flowers
- have flowers containing both male and female parts in the same flower

Plants can either self-fertilize or require cross-pollination from another plant.

3.6.2 Collecting pollen

Some pollinators actively gather pollen: Beetles, some bees. Others accidentally pick it up while gathering nectar: Most lepidopterans, flies, and bees. In either case, transfer of pollen between flowers is almost entirely incidental from the insect's point of view. That is, the insect is gathering food, and just so happens to also transport pollen between plants.

3.6.3 Flower Colour

Different pollinators are attracted to different colors of flowers. For example: Many red flowers are hummingbird pollinated, as insects do not see red well, Blue flowers tend to be bee-pollinated, Butterflies prefer white and yellow flowers. Since many bees see in UV, bee pollinated flowers often have markings visible in UV light.

Other Flower Attributes: Many fly-pollinated plants are smelly, Many butterfly- or moth-pollinated plants have long or thin nectar reservoirs

3.7 Plant – Insect Interaction II: Pitcher Plant Communities

A final example of a plant-insect interaction occurs in pitcher plants. Pitcher plants are carnivorous plants that contain water loaded with enzymes to digest arthropods that fall into the pitcher. The pitcher also contains a small community of insect larvae (plus other organisms) that live in the pitcher without being digested called the inquiline community

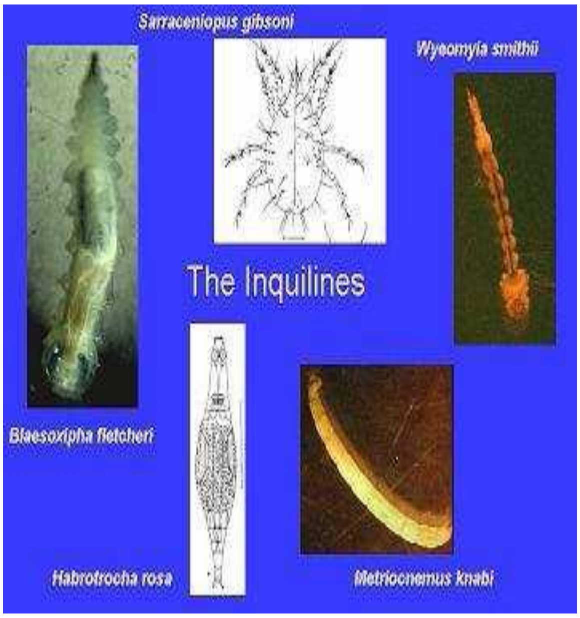

Fig. 9.19: A Pitcher Plant

Fig. 9.20: Various Inquilines (Squatters)

4.0 CONCLUSION

The importance of the insect-plant co-evolution is revealed in the benefits that both parties derive in the relationship as in Mutualism. Various features have been evolved by plants and insects in order compete well in this coevolution.

5.0 SUMMARY

Insect-Plant co-evolution can be described as an interaction between plants and insects which could be between a single plant and a single insect or between a single plant and a group of insect or between a group of insects and a group of closely-related plants.

The types of insect-plant coevolution are; mutualistic coevolution and “arms race coevolution. There are plant and insect aspects in coevolution. The major steps in the insect aspect are; finding a general habitat, finding the host plant, accepting the plant as a proper host and sufficiency of the plant for survival and successful reproduction of the insect population. In the plant aspect, both morphological and physiological characteristics of a plant elicit given insect responses.

Feeding is an example of plant-insect interaction. Here, there are various categories of phytophagous insects (insects eating plants) viz; leaf chewers, plant miners, plant borers, sap suckers, seed predators, nectar or pollen feeders and gall formers. Plants release chemicals upon being attacked by phytrophagous insects which signal predators of the herbivore to attack it. This release of chemicals is called induced defense. Other examples of plant-insect interaction include pollination and pitcher plant communities.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. describe insect-plant coevolution
2. discuss the type of coevoloution that exists between ants and *acacia*
3. explain the benefits and effects of the type of coevolution discussed in 2 above
4. state the various instances in which coevolution can exist between a plant and an insect
5. state with examples the types of plant borers
6. what is a gall?
7. Explain with annotated diagram the process of gall formation
8. Explain induced defenses in plant-insect interaction
9. Pollination is an example of plant-insect interaction. Describe with examples
10. Which type of coevolution exist between insects and pitcher plant communities?

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UNIT 2 PLANT RESISTANCE AND INSECT NUMBERS

CONTENTS

1.0 INTRODUCTION

In this unit, the concept of host plant resistance is treated. The types, mechanisms involved and the use of HPR in integrated pest management are discussed.

2.0 OBJECTIVES

At the end of this unit, you should be able to;

- Define host plant resistance
- Explain the types of plant resistance
- Describe the mechanisms of plant resistance
- Discuss HPR as a component in IPM
- Give examples of resistant varieties in major crops
- State the methods of developing resistant varieties

3.0 MAIN CONTENTS

3.1 Definition of Host Plant Resistance (HPR)

"Those characters that enable a plant to avoid, tolerate or recover from attacks of insects under conditions that would cause greater injury to other plants of the same species" (Painter, R.H., 1951).

"Those heritable characteristics possessed by the plant which influence the ultimate degree of damage done by the insect" (Maxwell, F.G., 1972).

Plant resistance to insects is a quality that enables a plant to avoid, tolerate or recover from the effects of oviposition or feeding that would cause greater damage to other genotypes of the same species under similar environmental conditions.

3.2 Types of Plant Resistance

3.2.1. Ecological resistance or Pseudo resistance

This results from transitory characters in potentially susceptible host plants due to environmental conditions. Sometimes called apparent resistance or pseudoresistance, usually is not considered true resistance. This is because expression of ecological resistance relies more heavily on environmental conditions than on genetics.

The characteristics of this resistance are temporary and the cultivars involved are potentially susceptible. Ecological resistance is important in insect pest management, but its use must be carefully synchronized with prevailing environmental conditions for effectiveness.

Pseudo resistance may be classified into 3 categories;

i) Host evasion (Phenological asynchrony)

With host evasion, the plant passes through a susceptible stage quickly or at a time such that its exposure to potentially injurious insects is reduced. This pertains to the whole population of host plant. Often, host evasion is accomplished by planting early maturing varieties. A good example is the planting of fast-fruiting, short-season cotton varieties in Texas to provide a long, host-free period for populations of the boll weevil, *Anthonomus grandis* and pink bollworm, *Pectinophora gossypiella*. The same varieties also give considerable evasion from populations of corm earworm and tobacco budworm, *Helicoverpa virescens*.

Sometimes evasion with early maturing varieties is confused with true resistance. To test early varieties for true resistance, they can be planted later than usual and inspected for late-season injury.

ii) Host Escape

It is the absence of infestation or injury to host plant due to transitory process like incomplete infestation. This pertains to few individuals of host. This category explains the lack of infestation of susceptible plants in a population of otherwise infested plants. The principle of host escape recognizes that the presence of an uninfested plant may not mean that it is resistant and emphasizes that escapes occur in most plant populations, even with heavy insect infestation. The reason for escapes is rarely understood

iii) Induced resistance

It is a temporary increase in resistance as a result of some changed conditions of plants or environment such as change in the amount of water or nutrient status of soil. It is a form of temporary resistance derived from plant condition or the environment. Factors like fertilization or changes in soil moisture levels may make plants more tolerant of insects than under other circumstances. For instance, nitrogen and potassium levels are known to affect aphid populations on plants. High nitrogen levels usually allow increases in survival, but the opposite may occur for high levels of potassium. Providing a proper balance of these nutrients in fertilizers has been suggested as a means of inducing resistance to aphids.

Recently, some attention has been given to the role of **phytoalexins** in inducing plant resistance to insects. Phytoalexins are phenolic compounds produced by plants when they become diseased or are attacked by insects. These compounds enable plants, once fed upon to resist further damage by the pests. The mechanism involved results from an accumulation of allomones triggered by the injury or some other environmental factor. For example, phytoalexin production in laboratory soybeans has been induced by inoculation with a fungus, *Phytophthora megasperma* variety *soja*. Subsequently, phytoalexin levels in cotyledons increased and functioned as feeding deterrents against larvae of the Mexican bean beetle, *Epilachna varivestis*.

3.2.2. Genetic resistance or True resistance

A. Based on number of genes

* *Monogenic resistance* : Controlled by a single gene. Easy to incorporate into plants by breeding. Easy to break also.
* *Oligogenic resistance*: Controlled by few genes
* *Polygenic resistance* : Controlled by many genes
* *Vertical resistance* (Major gene resistance) : Controlled by one or few major genes.
* *Horizontal resistance* (Minor gene resistance): Controlled by many minor genes. The cumulative effect of minor genes is called adult resistance or mature resistance or field resistance.

B. Based on biotype reaction

- *Vertical resistance*: Effective against specific biotypes (specific resistance). Specific to given biotypes (less stable).
- *Horizontal resistance*: Effective against all the known biotypes (Non specific resistance). Expressed equally to all biotypes of a pest.

C. Based on population / Line concept

- *Pureline resistance*: Exhibited by lines which are phenotypically and genetically similar

- *Multiline resistance*: Exhibited by lines which are phenotypically similar but genotypically dissimilar

D. Miscellaneous categories

- *Cross resistance*: Variety with resistance incorporated against a primary pest, confers resistance to another insect.
- *Multiple resistance*: Resistance incorporated in a variety against different environmental stresses like insects, diseases, nematodes, heat, drought, cold, etc.

E. Based on evolutionary concept

- *Sympatric resistance*: Acquired by co-evolution of plant and insect (gene for gene). Governed by major genes
- *Allopatric resistance*: Not by co-evolution of plant and insect. Governed by many genes

3.3 Mechanism of Plant Resistance

Resistant cultivars function in may different ways to reduce the effects on insect attack. Various steps are required in host selection by insects. For normal insect growth and development to occur, certain requisites, available in proper amounts and at specific times are necessary. Resistant cultivars, by one means or anther do not supply these requisites and thereby interrupt the normal host selection process. In some instances, the mechanism of resistance involves new allomones or increased level of existing ones; in others, it may be based on reduced levels of kairomones. Also, physical factors may be involved.

Most authorities consider true plant resistance as primarily under genetic control. In order words, the mechanisms of resistance derived from pre-adapted inherited characters. Therefore, the expression of these characters always occurs, although they can be mediated by environmental conditions.

The most widely accepted classification of genetic resistance modes in plants is that of R. H. Painter. These modes or mechanism are:

- Antixenosis (Non preference)
- Tolerance

- Antibiosis

3.3.1. *Non-preference (Antixenosis)*

This refers to plant characteristics that lead insects away from a particular host. It denotes presence of morphological or chemical factor which alter insect behaviour resulting in poor establishment of the insect. It includes activities of both plant and insect. It is also known as antixenosis meaning ‘against or expelling guests’.

With nonpreference, normal insect behavior is impaired in such a way as to lessen the chances of the insect’s using a plant for oviposition, food or shelter. e.g.

- Trichomes in cotton - resistant to whitefly
- Wax bloom on carucifer leaves - deter feeding by DBM
- Plant shape and colour also play a role in non preference
- Open panicle of sorghum - Supports less *Helicoverpa*

Non-preference can be expressed in a cultivar through either allelochemic or morphological characteristics.

a. *Allelochemic Non-preference*: This form of non-preference is common among plants, sometimes causing them to be totally rejected by insects. Allelochemic nonpreference occurs with insects like the spotted cucumber beetle, *Diabrotica undecimpunctata howardi*, and other *Diabrotica* species on cucurbits. In this insect/plant relationship, cucurbitacins (a class of tetracyclic terpenes) produced by cucurbits act as attractants and feeding incitants for the beetles. Cultivars that lack or display low levels of specific cucurbitacins attract fewer beetles and receive much less damage than those with the feeding requisite.

b. *Morphological Non-preference*: This form of non-preference results from plant structural characteristics that disrupt normal behavior by physical means. As an example, the corn earworm, *Helicoverpa zea*, an important pest of many field and garden crops prefers to oviposit on pubescent surface. Experiments involving cotton genotypes that lack hairs have shown that these genotypes suffer much less damage by many insect species because of lower than normal rates of oviposition. Feeding activity is also diminished in many instances by morphological factors including pubescence, tissue characteristics and gummy exudates. As examples, husk tightness in corn resists damage from corn earworms, stem density of pith and node tissues in wheat resists damage by the wheat stem saw-fly (*Cephus cinctus*) and hard, woody stems with closely packed vascular bundles in cucurbits resist feeding of the squash vine borer, *Melittia cucurbita*e.

Use of Non-preference

In a practical sense, the use of some nonpreference characteristics may be limited by given cultural environments. Many cultivars may show nonpreference if alternate hosts are in the vicinity but in the absence of alternate hosts, the nonpreference may break down. The insect species does not particularly prefer the cultivar, but if nothing else is available, it will accept it. Be cause of the widespread practice of monocropping and the breakdown of resistance, allelochemic nonpreference is not a primary goal in plant breeding programmes.

On the other hand, forms of morphological nonpreference that impair feeding behavior are very important and may be a first line of defense against many pests. This is partly because morphological nonpreference provides long lasting effectiveness, compared with most chemically based resistance; that is, insect populations have a difficult time overcoming this form of resistance.

3.3.2. *Tolerance*

It is the ability to grow and yield economically despite pest attack. Unlike nonpreference and antibiosis, only a plant response is involved in tolerance. The plant has the ability to give satisfactory yield in spite of injury levels that would debilitate nonresistant plants. This is the least dramatic resistance mechanisms and some plant scientists do not consider it a form of resistance.

Many factors are involved in plant tolerance yet the overall mechanisms are poorly understood. Known components of this form of resistance include;

- General vigour
- Compensatory growth in individual plants and/or the plant population

- Wound healing
- Mechanical support in tissues and organs and
- Changes in photosyntate partitioning.

An important **advantage** of tolerance is that it places no selective pressure on insect populations as do antibiosis mechanisms. Without selection pressure, variants do not develop that can overcome the resistance.

Its **disadvantage** is that insect populations may be allowed to sustain epidemics in an area causing problems in other groups. Also, producers are wary of recommendations that allow large populations of seemingly injurious species build up. Another perhaps more important disadvantage is that tolerance is more strongly affected by environmental extremes than are other forms of resistance.

An example of tolerance is found in several corn genotypes that have the ability to repair and replace roots fed upon by the western corn rootworm, *Diabrotica virgifera*. Such tolerance allows plants adequate e water and nutrient uptake and anchorage despite heavy feeding. Surprisingly, tolerant genotypes developed grater root volume with rootworm feeding than without. In addition to corn, tolerant cultivars have been observed in many crops including alfalfa, barley, cassava, cotton, rice, sorghum and wheat.

3.3.3. *Antibiosis*

This is the adverse effect of the host plant on the biology (survival, development and reproduction) of the insects and their progeny due to the biochemical and biophysical factors present in it. By far, antibiosis is the most widely sought after objective of plant breeders. This mechanisms usually impairs an insect's' metabolic processes and often involves consumption of plant metabolites. As with nonpreference, both insect and plan factors are involved in the antibiosis mechanism.

Allelochemics are frequently associated with antibiosis. Some of the best documented allelochemics include the cyclic hydroxamic acids in corn (DIMBOA), gossypol and related compounds in cotton, steroidal glycosides in potato and saponins in alfalfa.

Quantity and quality of primary metabolites may also be important in conferring antibiosis. Particularly significant in this regard are imbalances for sugars and amino acids that result in nutritional deficiencies for insects feeding on the plant. For example, pea cultivars with low amino acid levels and increased sugar content show resistance to the pea aphid, and rice cultivars deficient in asparagines (an amino acid) cause reduced fecundity in the brown planthopper, *Nilaparvata lugens*.

Symptoms of insects affected by antibiosis include;

i. Death of young immature
ii. Reduced growth rates
iii. Increased mortality in pupal stage
iv. Small adults with reduced fecundity
v. Shortened adult life span
vi. Morphological malformations
vii. Restlessness and other abnormal behaviour

Antibiosis may be due to :
- Presence of toxic substances
- Absence of sufficient amount of essential nutrients
- Nutrient imbalance/improper utilization of nutrients

Chemical Factors In Antibiosis – Examples

S/N	**Chemicals present in plants**	**Imparts resistance against**
1.	DIMBOA (Dihydroxy methyl benzoxazin)	Against European corn borer, *Ostrinia nubilalis*
2.	Gossypol (Polyphenol)	*Helicoverpa armigera* (American bollworm)
3.	Sinigrin	Aphids, *Myzus persicae*
4.	Cucurbitacin	Cucurbit fruit flies
5.	Salicylic acid	Rice stem borer

Physical Factors In Antibiosis

Thick cuticle, glandular hairs, silica deposits, tight leaf sheath, etc.

3.4 HPR in Integrated pest Management (IPM)

HPR is a very important component of IPM. Selection and growing of a resistant variety minimize cost on all other pest management activities.

3.4.1 Compatibility of HPR in IPM

i. Compatibility with chemical control

- HPR enhances efficacy of insecticides
- Higher mortality of leaf hoppers and plant hoppers in resistant variety compared to susceptible variety
- Lower concentration of insecticide is sufficient to control insects on resistant variety

ii. Compatibility with biological control

- Resistant varieties reduce pest numbers - thus shifting pest: Predatory (or parasitoid) ratio favourable for biological control. e.g. Predatory activity of mirid bug *Cyrtorhinus lividipennis* on BPH was more on a resistant rice variety IR 36 than susceptible variety IR 8
- Insects feeding on resistant varieties are more susceptible to virus disease (NPV)

iii. Compatibility with cultural method

Cultural practices can help in better utilization of resistant varieties. e.g. Use of short duration, pest resistant plants effective against cotton boll weevil in USA.

3.4.2 Advantages of HPR as a component in IPM

1. *Specificity*: Specific to the target pest. Natural enemies unaffected
2. *Cumulative effect*: Lasts for many successive generations
3. *Eco-friendly*: No pollution. No effect on man and animals
4. *Easily adoptable*: High yielding insect resistant variety easily accepted and adopted by farmers. Less cost.
5. *Effectiveness*: Res. variety increases efficacy of insecticides and natural enemies

6. *Compatibility*: HPR can be combined with all other components of IPM
7. *Decreased pesticide application*: Resistant varieties requires less frequent and low doses of insecticides
8. *Persistence*: Some varieties have durable resistance for long periods
9. *Unique situations*: HPR effective where other control measures are less effective e.g.
   a. When timing of application is critical
   b. Crop of low economic value
   c. Pest is continuously present and is a single limiting factor

3.4.3 Disadvantages of HPR as a component in IPM

1. *Time consuming*: Requires from 3-10 years by traditional breeding programmes to develop a resistant variety.
2. *Biotype development*: A biotype is a new population capable of damaging and surviving on plants previously resistant to other population of same species.
3. *Genetic limitation*: Absence of resistance genes among available germination

3.5 Examples of Resistant Varieties In Major Crops

Plant / Crop	**Pest**	**Resistant Varieties**
Rice	Yellow stem borer	TKN 6, Paiyur-1, Vikas, Ratna, Sasyasree
	Brown planthopper (BPH)	Co 42, IR 36, IR 64, PY 3, Ptb 33
	Green leaf hopper (GLH)	IR 50, Ptb 2, 18, Co 46, CR 1009
	Gall midge	MDU 3, Udaya, Shakti, Vikram
Sugarcane	Early shoot borer (ESB)	Co 312, Co 421, Co 661, Co 917, Co 853
	Internode borer	Co 975, Co 7304, CoJ 46
	Top shoot borer	Co 745, Co 6515

	Mealy bug	Co 439, Co 443, Co 720, Co 730
Cotton	American bollworm	Abhadita
	Spotted bollworm	Deltapine, Hopi
	Stem weevil	MCU 3, Supriya
	Leaf hopper	MCU 5, K 7, K 8, Pk 719, Pk 688, Pk 1717, SRT 1
	Whitefly	Kanchana
Sorghum	Earhead bug	K tall
	Shootfly : Co	Shootfly : Co
Jasmine	Eriophyid mite	Pari Mullai
	Aphids	Annamalai Scale : Co 439, Co 443, Co 671, Co 691, Co 692

3.6 Methods of Developing Resistant Variety

1. Screening of available germplasm

Available germplasm collections are sown in a single row in a location at a time and evaluated where there is a moderate to heavy incidence and the incidence may be compared by growing a susceptible variety.

2. Selective screening under natural infestation

Select promising lines from general screening and screen under natural condition in a single row or 2-3 rows in replicated trials.

3. Selective screening under artificial condition

To test true resistance, the selected varieties are screened under artificial condition in which insects are bombarded over the plant. Results are compared with a resistant and susceptible check. Breeders start screening it from F_2 - F_6 stages for yield and resistance. If found suitable they will be forwarded to multilocation trial (MLT) and for Adaptive Research Trials (ART). If a line/cultivar succeeds in all stages, it will be released as a variety.

4.0 CONCLUSION

Host plant resistance as discussed can be utilized widely in pest management. The compatibility of HPR in IPM has also been discussed with their advantages and disadvantage.

5.0 SUMMARY

Plant resistance are those characters that enable a plant to avoid, tolerate or recover from attacks of insects under conditions that would cause greater injury to other plants of the same species. The types of plant resistance are; ecological or pseudo resistance which may be further classified into 3 categories (host evasion, host escape and induced resistance) and genetic or true resistance. The mechanisms of plant resistance are; antixenosis, tolerance and antibiosis. Methods of developing resistant variety; screening of available germplasm, selective screening under natural infestation and selective screening under artificial condition.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. Define host plant resistance

2. Differentiate pseudo resistance from true resistance

3. Explain the terms;

a. Phenological asynchrony
b. Host escape
c. Induced resistance
d. Pureline resistance
e. Multiline resistance
f. Cross resistance
g. Multiple resistance
h. Sympatric resistance
i. Allopatric resistance

4. Discuss the use of non-preference

5. State the advantage and disadvantage of tolerance

6. What are the symptoms exhibited by insects affected by antibiosis

7. Mention the chemical and physical factors involved in antibiosis

8. Explain the use of host plant resistance in integrated pest management

9. State the methods of developing resistant varieties

7.0 FURTHER READING / REFERENCES

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http//kali.usask.ca/bio364/essay97/sa97203/sa97203.html
concepts of host-plant resistance to insects with emphasis on genetics and genetic engineering of insect-resistant crops

http://www.ipmwprld.umn.edu/chapters/teetes.htm
Principles of plant resistance to insects, focusing on specific examples of sorghum resistance to sorghum midge and greenbug

http://sustainable .tamu.edu/slidesets/ipm/ipm30.html
Examples of plant varieties resistant to insects, with colour photos.

UNIT 3 INSECT-INSECT RELATIONSHIPS

CONTENTS

1.0 INTRODUCTION

Insect-insect relationships is not a recent evolution. Scientists have been studying this and utilized this in pest management practices. In this unit, the two forms of insect-insect relationships, their examples and how they are practised are treated.

2.0 OBJECTIVES

At the end of this unit, you should be able to;

- Discuss the history of insect-insect relationships
- Explain insect predator-prey relationships
- Describe insect parasitoid-host relationships
- Discuss succinctly the various techniques used by insect in both forms of insect-insect relationships with named examples

3.0 MAIN CONTENT

3.1 History of Insect – Insect Relationships

Success in controlling pests by marshalling beneficial insects to "battle" them was first recorded in 1775. In that year, a report by the Swedish naturalist Peter Forskal told how the date growers of Yemen had been observed to use one kind of ant to kill another which was destructive to the trees.

The use of beneficial ants to protect orchards from insect pests has long been practiced in Asiatic countries. A report in 1936 says citrus growers of south China put bamboo runways between the trees to aid the ants in their movements from tree to tree. Almost a century passed after the publication of Forskal's report before pest-killing insects tested by bona fide scientists were transported from one country to another. In 1873, a mite (*Tyroglyphus phylloxerae Riley*) was shipped from the United States to France for the control of the grape phylloxerae. ln the next year the lady bird (*Coccinella undecimpuctata L.*) was introduced into New Zealand from England. A third insect *Apanteles glomeratus L.* a parasite of the cabbage worm was sent to the United States from England in 1883 and likewise proved successful.

Nevertheless these efforts were scattered over ten years and the true beginning of the sustained biological control movement did not come until l888 and 1889 when Albert Koebele traveled to Australia for the U.S. Department of Agriculture to secure natural enemies of the cottony cushion scale. At this time this pest was killing so many large branches of citrus trees in California that the industry was threatened with extinction. Banks refused to accept infested groves as collateral for loans.

Albert shipped back some ladybirds (*genus Rodalia*) which readily killed cottony cushion scale and thrived over the winter in the groves. Propagating, they quickly reached adequate numbers to check the pest and to this day their descendants - together with those propagated in the insectaries and released - have kept the scale under control. All told, the introduction of this insect probably did not cost the government more than $5000 including the salaries of the scientists.

For 25 years, Koebele, the first of the entomological explorers, was engaged in importing parasites. He worked for the U. S. Department of Agriculture, then for the California State Board of Horticulture, and finally for the Hawaii Board of Agriculture and Forestry.
Contemporary with him was George Compere of the California Board of Horticulture, who from 1899 to 1901 traveled to the Far East and Australia in search of scale insect parasites and predators. Following this, from 1901 to 1904 he served the Government of West Australia in finding and importing parasites of fruit flies. So valuable were his services that from 1904 to 1910, California and Australia employed him jointly. His quests for insects beneficial to crops took him around the world.

Both Koebele and Compere were self-trained naturalists. Not so Frederick Muir, the remaining pioneer, who had a hand in setting biological control on a firm footing. Technically trained, he began exploratory work in 1905 for the Hawaiian Sugar Planters' Experiment Station. He was especially eager to find shock troops that would attack the sugar-cane beetle borer, *Rhabdoscelus obscurus*. Tracing down this and that clue, he found at long last at Amboina, in the South Sea Islands, the insect *Macroceromasia sphenophori*. This, he had reason to believe, would curtail the pest, and after prolonged effort, he was able to transport it alive to Hawaii, where it met with great success in the purpose intended. In turn, those who have followed Muir have been specialists, devoting themselves quite closely to specific problems. For instance, in California, the Citrus Experiment Station took a special interest in a shipment in 1927 of two parasites (*Tetracnemus pretiosus* and *Coccophagus gurneyi*) from Australia for the control of the citrophilus mealy bug. Already it had spread to 70,000 acres of Valencia oranges.

By l930, the imported parasites had put this pest out of the picture as an economic factor. They have probably saved citrus growers more than $1,000,000 a year. Yet the total cost to the university of California for the search, importation, and establishment of the beneficial parasites did not exceed $10,000. On September 30, 1942, agricultural officials who were making a routine inspection of a peach orchard in Southern California's Orange County found an insect larva that differed from any they had heretofore collected. When they identified it as the oriental fruit moth, the State's economic entomologists and agricultural administrators were alarmed. They knew well that since 1915, when this moth was first discovered in the United States near Washington, D. C., it had built up a record of increasing destructiveness to peaches. As an indication of the extent of its damage, in South Carolina it has rendered 12 per cent of the peaches unmarketable. In some eastern orchards the losses to individual growers have reached 50 to 100 per cent.

The wormlike larva of this moth burrows into the tips of growing shoots, causing the terminal leaves to wilt and die. Or it tunnels into the fruit itself, producing the well known "wormy peach." It had now spread from the Atlantic seaboard to the Pacific coast. In view of California's extensive production of late canning peaches, it looked as though the fruit growers were in for a hard time. Fortunately, as early as 1917 a native ichneumon "fly," *Macrocentrus ancy1ivorus*, in reality a wasp, was observed to be playing an important part in the natural control of the moth in a limited area on the Atlantic coast. By 1929, this insect had clearly shown its worth from southern Connecticut to southern Virginia by destroying as high as 90 per cent of the larvae infesting the twigs. As the oriental fruit moth spread westward, the United States Bureau of Entomology and Plant Quarantine nurtured the parasite in their laboratory at Moorestown, New Jersey. In co-operation with the various state agencies, they liberated it wherever the fruit moth advanced in sufficient numbers. Rusty-yellow in color and about equal to a mosquito in size, the female of this ichneumon fly possesses an ovipositor about as long as her body. When ready to lay her eggs, she crawls over the twig or fruit until she finds the web or excrement of the larva. She then unsheathes her ovipositor and with it locates the hole by which the larva burrowed in. Her ovipositor contacts the larva, and she quickly pierces its skin and injects into its blood a minute egg. As soon as the egg is immersed in blood, it begins to absorb food. In time it hatches, and the fruit moth larva is ultimately killed.

The value of this fly can best be realized by the fact that under proper temperatures the female can lay eggs approximately 24 hours after emerging as an adult, and her average life cycle is about 34 days, during which she may deposit over 500 eggs. She may waste more than one egg on one fruit moth larva, but still the destruction is great. When released in an orchard, she searches diligently for infested trees. After depositing eggs in one locality, she may travel as much as six miles to other trees.

A method for producing the beneficent parasites was successfully worked out, and in 1946, almost 29 million of them were produced. About 23 million were shipped to orchardists in 14 counties. Aside from a few backyard trees in one section, the oriental fruit moth vanished as a problem, and it has not reappeared. Should it do so, the University of California now has at its command the "assembly line" to produce a redoubtable natural enemy. And the cost, compared with the potential value, was extremely low.

Another recent contribution of the Citrus Experiment Station had to do with the California red scale. For more than half a century, this scale, *Aonidiella aurantii*, had annually wrought great damage on the trunks, branches, and foliage of citrus trees. In several test orchards it was shown that it might be possible to reduce the infestation by means of two species of tiny wasps. These were the so called golden chalcid "fly" and its relative from China, *Aphytis "A."* These wasps parasitized the scale and also killed many of the invaders by sucking the body fluids through a strawlike wax tube formed with the aid of the ovipositor. This was the first indication that the scale might be satisfactorily controlled by methods other than the use of insecticides.

The Station further learned that under favorable conditions the wasps may control the scale much more cheaply than insecticides. When production methods are refined still further, it may cost less than $40 to raise 400,000 wasps - the quota per acre necessary to give biological control in all but heavily infested groves during the first year after the insecticidal treatment is stopped. Control by insecticides costs approximately $50 an acre. In addition, the use of insecticide is a yearly proposition, whereas the insect "police," once they are generally established, will increase through natural reproduction, thus taking the strain off the insectary. In many groves, a natural balance may then ensue.

In the introduction of natural allies from abroad, great care is exercised to avoid releasing any imported species that might possibly prove detrimental. As Dr. Stanley E. Flanders of the University of California puts it, "We make sure that the parasite or predator has the fixed habit of attacking the pest for which it is employed and that it cannot become a problem in some other way. Imported insects, whether noxious or beneficial, are apt to run rampant when introduced into a favorable environment." The answers to over 50 different questions are sought concerning the habits and inclinations of any insect being considered as a possible clean-up corps.

In citing these achievements, scientists freely admit that numerous other projects have not been so successful and that the expense of them must be added to the cost of the successful ones. Nevertheless, they point out that the successes eclipse the failures many times over.
Further, they wish to make it clear that their advocacy of the use of beneficial insects to destroy injurious ones does not imply that this method will supplant altogether the employment of insecticides. They warn rather that in our enthusiasm for sprays and fumigants, we must not overlook the possibilities of utilizing potential pest-destroying insects. They contend that the maximum exploitation of both methods - biological and artificial control - is needed in the war of man-versus insect pests.

3.2 Insect Predators

Insect predators comprise approximately 10% of all insects. Predatory insects have striking adaptations for detecting, tracking, capturing and killing their prey. Some predatory insects use sit-and-wait tactics, others actively forage for their prey, and others use lures to attract unwary prey. Predatory insects are important in biological control (e.g., lady bugs). In this lecture we will examine the diversity of predator strategies and the ways predators can be used in agricultural settings.

Predators catch and eat their prey. Some common predatory arthropods include ladybird beetles, carabid (ground) beetles, staphylinid (rove) beetles, syrphid (hover) flies, lacewings, minute pirate bugs, nabid bugs, big-eyed bugs, and spiders.

Fig. 11.1: Preying mantid consuming insect prey.

3.3 Insect Parasitoids

A parasitoid is an organism that spends a significant portion of its life history attached to or within a single host organism in a relationship that is in essence parasitic; unlike a true parasite, however, it ultimately sterilises or kills, and sometimes consumes, the host. Thus parasitoids are similar to typical parasites except in the more dire prognosis for the host.

Parasitoids (sometimes called parasites) do not usually eat their hosts directly. Adult parasitoids lay their eggs in, on, or near their host insect. When the eggs hatch, the immature parasitoids use the host as food. Many parasitoids are very small wasps and are not easily noticed. Tachinid flies are another group of parasitoids. They look like large houseflies and deposit their white, oval eggs on the backs of caterpillars and other pests. The eggs hatch, enter the host, and kill it. Parasitoids often require a source of food in addition to their host insect, such as nectar or pollen.

Fig. 11.2. Braconid Wasp Cocoons On Giant Leopard Larva.

Parasitoids are parasitic insects whose larvae develop by feeding in, or on, the bodies of other host insects (called arthropods). We make the following general assumptions about the interaction of the host and parasitoid species:

1. hosts that escape parasitism give rise to the next generation of hosts
2. the fraction of hosts that are parasited is a function (to be specified) of the rate of encounter of the two species
3. the next generation of parasitoids come from parasited hosts

About 10% of described insect species are entomophagous parasitoids. There are four insect orders that are particularly renowned for this type of life history. By far the majority are in the order Hymenoptera.

The largest and best-known group comprises the so-called "Parasitica" within the Hymenopteran suborder Apocrita: the largest subgroups of these are the chalcidoid wasps (superfamily Chalcidoidea) and the ichneumon wasps (superfamily Ichneumonoidea), followed by the Proctotrupoidea and Platygastroidea. Outside of the Parasitica, many other Hymenopteran lineages that include parasitoids, such as most of the Chrysidoidea and Vespoidea, and the rare Symphytan family Orussidae.

The flies (order Diptera) include several families of parasitoids, the largest of which is the family Tachinidae, and also smaller families such as Pipunculidae, Conopidae, and others. Other families of flies that are not primarily parasitoids or parasites, or at least not primarily protelean, do nonetheless include protelean species. For example Phoridae have already been mentioned as parasitoidal on ants, and at least some flesh fly species, such as Emblemasoma auditrix, are parasitoidal on cicadas, and have raised great interest because they locate their hosts by sound.[19] The kleptoparasitic flesh fly genus *Craticulina* has already been mentioned and logically qualifies as a protelean fly genus.

Two other orders with parasitoidal members are the "twisted-wing parasites" (order Strepsiptera), which is a small group consisting entirely of parasitoids, and the beetles (order Coleoptera), which includes at least two families, Ripiphoridae and Rhipiceridae, that are largely parasitoids, and rove beetles (family Staphylinidae) of the genus *Aleochara*. Occasional members of other orders can be parasitoids; one of the more remarkable is the moth family Epipyropidae, which are ectoparasitoids of planthoppers and Cicadas. The genus Cyclotorna has even more elaborate habits, beginning its growth period parasitising plant bugs, and concluding by feeding on ant larvae in their colonies.

Hymenopteran parasitoids often have unique life cycles. In one family, the Trigonalidae, the female wasps deposit eggs into small pockets they cut into the edge of leaves with their ovipositor. A caterpillar chewing these leaves may unknowingly swallow some of the eggs, and when they get into the caterpillar's gut, they hatch and burrow through the gut wall and into the body cavity. Later they search the caterpillar's body cavity for other parasitoid larvae, and it is these they attack and feed on. Some trigonalids, once in a caterpillar or sawfly larva, need their vehicle to fall prey to a social wasp. The wasp carries the caterpillar back to its nest, and there it is butchered and fed to the wasp's young; they will serve as the host for the trigonalid, the eggs of which are in the butchered caterpillar.

3.4 Insects as Predators and Parasitoids

3.4.1 Host/prey location and acceptance

1. Random searchers roam in the appropriate microhabitat and capture prey upon contact. Examples of microhabitats include leaf edges, veins, stems, flowers, etc.

a. After an initial contact or meal, further searching involves more frequent turns resulting in the predator remaining in the same general location.

b. Random searchers are the most common type of insect predator.

c. Examples include most coleopteran predators, coccinellids, syrphid larvae, and lacewings.

2. Hunting, or directional foraging differs from random searching by using sight or other stimuli to orient to prey from a distance.

a. Many hunters initially identify prey items via vision.
i. A sphecid wasp that preys upon bees will attack any flying object that is approximately the same size as a bee but will only sting an actual bee suggesting that tactile stimuli are used at close range.
ii. Robber flies and dragonflies have enormous eyes for detecting prey items in flight.

b. Initial host location may also occur via chemical cues.
i. Many predators use chemical signals produced by the prey for intraspecific communication.
• Parasitic tachinid flies and braconid wasps locate their respective stink bug or coccoid host by following their hosts' long-distance sex attractant pheromones.

• Parasitoid hymenopterans follow the aggregation pheromones of their bark and timber beetle hosts.

ii. Other predators locate hosts by detecting chemicals emitted from stressed or insect damaged plants.

• Parasitoids of the scolytid timber beetles cue into the terpenes that are released from the infested pine trees.

iii. Just as phytophages find their host plants by volatile chemicals, predators of these phytophages also are attracted by these chemicals.

iv. Some parasitoids can even detect frass odors of their insect larval hosts.

c. Host location is also accomplished by detecting sound.

i. Tachinid parasitoids of some crickets find their hosts by listening to the cricket's calls

ii. Sarcophagid parasitoids of cicadas do likewise.

iii. Ceratopogonid biting midges find swarms of prey midges by detecting the sounds produced by wing-beat frequencies.

d. Phoresy is a unique method of host location that involves "hitch-hiking."

i. A predator or parasitoid jumps onto another insect that carries it to a new location.

ii. The new location may place the predatory insect in close proximity to a new host or prey.

• One species of blood-sucking ectoparasitic fly of some birds transport avian lice (Phthiraptera) from one bird nest to another.

• Many egg parasitoids attach themselves to adult females of the host species, thereby gaining instant access to her eggs.

iii. Other phoretic species attach to and are carried back to the nest of the transport species.

• Some chalcid hymenopterans have larvae that actively seek out worker ants, to which they attach and eventually burrow into ant grubs or pupae within the nest.

• Female bot flies capture mosquitoes, hold them in such way to prevent injury, then place around 30 eggs on the undersurface, which will not interfere with flight. The mosquito then carries the bot fly eggs to a vertebrate host. The elevation of temperature associated with the vertebrate host induces the eggs to rapidly hatch and fall onto the host.

3. Ambush, or 'lie-n-wait' predators remain in one place and strike at acceptable prey when they come within range.

a. Many insects' vision is limited to recognition of movement so that a non-moving predator is undetectable to a potential prey organism.

b. However many ambush predators are also cryptic, resembling things like bark, lichen, or leaves.
c. Other ambush predators mimic an object that prey are attracted to like flowers.

d. Odonate larvae rest concealed in submerged vegetation or on the substrate waiting for prey to pass by.

e. One form of ambush also involves hunting tactics. Dragonfly adults often sit perched on vegetation, then dart out and capture prey on the wing much like the flycatchers of the bird world.

f. Hypermetamorphic larvae are common within the parasitoid taxa. These larvae are active as first instars, seek out and find hosts, then metamorphose into relatively inactive, non-motile larvae. These larvae will metamorphose again at pupation.
i. Meliod beetle larvae are hypermetamorphoic and active. They attach to desert bees that then transport them to their nests.
ii. Many tachinids eggs hatch into hypermetamorphic larvae.

4. Trappers are predators that construct traps in which to capture prey.

a. This could be considered a form of ambush the predator waits near the trap then pounces on the prey once it is ensnared in the trap.

b. Ant lion larvae are the classic example.

c. Larvae of the glowworm, a type of gnat, live in moist caves. They spin slimy webs that dangle from the ceiling. The larvae rest behind the web and are bioluminescent, attracting prey into the web. Some forms of this gnat produce a web that is not only sticky but contains toxic chemicals.

d. Hydropsychid caddisfly larvae also construct nets in which to trap prey.

e. Some smaller assassin bugs of the subfamily Emesinae wait near spider webs and steal the trapped prey from the spider.

3.4.2 Host/prey acceptance and manipulation

1. Prey acceptance and manipulation by predators

a. A step-by-step sequence of stimuli is usually necessary for prey location and acceptance and may involve the shape of the prey, chemical coatings on the prey, and volatile chemicals produced by a host plant of the prey.

b. Often size and/or the age of the potential prey/host are assessed.

c. Chemical and tactile stimuli are involved in species identification and may include the predator biting or piercing the potential prey.

d. Predators must be able to restrain their prey while killing it. This is often accomplished using raptorial forelegs as in mantids, modified hind legs as seen in some scorpionflies, or the labial mask of odonate nymphs.

e. Mouthparts of predators are of two general types.
i. Modification of various elements (labrum, labial palps, labium, maxillae, hypopharnyx) of the head and mouthparts forms piercing-sucking mouthparts with stylets that are either slender and needle like or knifelike.
ii. The mandibles are strengthened and elongate.

f. Many predators with piercing-sucking mouthparts also inject enzymes into the prey then suck up the predigested liquid (extraoral digestion). Only material that is digestible is taken into the body. This is obviously more efficient than eating the organism whole.

2. Host acceptance and manipulation by parasitoids

a. Initially chemoreceptors in the antennae signal information as to the appropriateness of the potential host.
i. Many parasitoid Hymenoptera sport relatively long antennae.
ii. Species identification is confirmed by chemoreceptors located on the ovipositor of the female parasitoid.
iii. Parasitoids of wood-boring insects must find their host strictly using chemoreceptors on the ovipositor (ichs on siricids).

b. Size and/or the age of the potential host are also assessed.
i. Many parasitoids reject old larvae that are close to pupation, while others seek out the biggest, oldest larvae.

3. Host immune responses

a. The usual host reaction to a parasitoid egg or larva is encapuslation by aggregating haematocytes. Phagocytosis usually follows.

b. Parasitoids in their normal host have evolved ways to avoid encapusulation.
i. Avoidance: The parasitoid resides in a particular organ like the brain, a ganglion, a salivary gland or the gut and thus escape the immune reaction of the host haemolymph.
ii. Evasion: The parasitoid is a molecular mimic to the host proteins and is not recognized by the host as being non-self, or the parasitoid insulates itself in a membrane or capsule, or development is so rapid that the host cannot respond in time to encapsulate.
iii. Suppression: The host cellular immune responses may be suppressed by viruses associated with the parasitoid.
iv. Subversion: The parasitoid is resistant to encapsulation and/or the capsule is subverted for use as a sheath.

4.0 CONCLUSION

In this unit, the history of insect-insect relationships and their utilization have been discussed. Also, the main order of insects involved in these type of relationships have being treated alongside the techniques used by these insects.

5.0 SUMMARY

Predators kill and consume more than one prey organism to reach maturity. Parasitoids require only one host to reach maturity, but ultimately kill the host. True parasites feed on one or more hosts, but do not normally kill the host.

Nearly every order of insect contains predatory species. Some species are only predatory as immatures, others as adults, and still others are predatory throughout their life span. Some orders are nearly entirely predatory like the Odonata, the Mantodea and the Neuroptera.

6.0 TUTOR-MARKED ASSIGNMENT

1. Briefly discuss the history of insect-insect relationships
2. What are the assumptions made with respect to the interaction between host and parasitoid species
3. Give examples of predator-prey and host-parasitoid relationships amongst insects
4. Mention the specific orders of insects that are involved in these relationships
5. Explain the techniques used by insect predators and parasitoids

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UNIT 4 MANIPULATING INSECT BEHAVIOUR

CONTENTS

1.0 INTRODUCTION

An insect is considered a pest if it threatens a resource valued by humans, including human health. Protection of a resource from a pest is usually achieved by poisoning the pest with a toxic pesticide, but it can also be achieved by manipulating a behavior of the pest. The manipulation of a pest's behavior to protect a resource is not a new concept. The practice of trap cropping, i.e. using a sacrificial resource for the pest to attack, in order to protect a valued resource, has been known for centuries. However, in the last 30 years or so, largely due to improvements in analytical techniques and an increased desire to reduce the reliance on broad-spectrum insecticides, there has been increased interest in behavioral manipulation for pest management.

2.0 OBJECTIVES

At the end of this unit, you should be able to;

- Explain insect behavioural manipulation methods
- Give examples of behavioural manipulation methods
- Describe attract – annihilate method
- Discuss stimuli acting at close distance

3.0 MAIN CONTENT

Virtually all methods of pest management involve some changes in pest behavior, whether intentional or not. The manipulation is defined as the use of stimuli that either stimulate or inhibit a behavior and thereby change its expression. This definition excludes some areas in which changes in pest behavior are advantageous to pest management, notably those resulting from sublethal effects of toxic chemicals or substances that induce a gross change in physiology and those that merely consider the pest's behavior, as in planting a crop out of synchronization with the pestilential behavior.

3.1 Behavioural Manipulation Methods

There are three principal elements of a behavioral manipulation method:

- a behavior of the pest,
- a means by which the behavior is manipulated appropriately, and
- a method that utilizes the behavioral manipulation for protection of a resource from the pest.

In theory, any behavior of any stage of the pest can be chosen, provided that its manipulation protects the resource. Intuitively, one might expect that manipulation of a pestilential behavior (e.g. feeding on the resource) or a behavior closely related to the pestilential behavior (e.g. finding the resource) is more likely to be useful for pest management than manipulation of behaviors unrelated to the resource (e.g. mating). Successful manipulation of the pestilential behavior will ensure protection of the resource; successful manipulation of an unrelated behavior may reduce the local population but still not protect the resource because of immigration of outside populations into the area being protected, as can occur in the mating disruption method for moths. In practice, however, the criterion by which a behavior is usually chosen for manipulation is not its relationship to the pestilential behavior but rather the availability of an appropriate means for its manipulation.

The behavior of an insect results from the integration by its central nervous system of a variety of inputs that derive from stimuli acting on exteroceptors (which sense events external to the insect), enteroceptors (which sense the internal physiological state of the insect), and proprioceptors (which sense the relative positions of parts of the body). To manipulate a behavior one must change either the inputs or the processing of those inputs by the central nervous system. At present the latter approach is generally inaccessible for effecting deliberate manipulation of a behavior, although it may occur in some instances as a sublethal effect of a toxic insecticide. Thus, insect behavior generally is manipulated through inputs to the behavior and more specifically through the stimuli that generate these inputs.

The choice of a stimulus to use for behavioral manipulation is usually dependent upon a number of attributes including the following;

1. *Accessibility*. The stimulus must be suitable for presentation in a form that the insect can perceive.
2. *Definability and reproducibility*. The more precisely that the stimulus can be defined, the more precisely it can be reproduced artificially.
3. *Controllability*. The ability to control various parameters of a stimulus, including intensity and longevity, will give greater control in a behavioral manipulation.
4. *Specificity*. The more specific a stimulus is to a particular behavior of a pest, the more likely it can be used to manipulate that behavior. Conversely, a stimulus that is ubiquitous in the environment is unlikely to be useful for manipulating specific behaviors unless its intensity or quality can be perceived by the insect above the background level. For example, “supernormal” visual targets (i.e. objects that reflect high ratios of stimulatory to inhibitory wavelengths of light) are used to outcompete the natural visual background reflecting a lower ratio of stimulatory to inhibitory wavelengths.
5. *Practicability*. Environmental hazards and cost of protecting a resource must be within practical limits. For example, chemicals that are persistent and have high mammalian toxicities may protect an edible resource but render it useless for human consumption.

In light of these desirable attributes, it is not surprising that the use of stimuli acting on exteroceptors predominates over the use of stimuli acting on enteroceptors (internal stimuli). For the most part, internal stimuli are inaccessible for behavioral manipulation and are difficult to define and control. The listed attributes also support the much greater use of chemicals compared to other external stimuli used in behavioral manipulation. In addition to the listed attributes, chemicals are used more often because of their involvement in many insect behaviors, their familiarity because of wide use in pest control, and the advances over the last 30 years in techniques to analyze chemicals involved in insect behavior.

In contrast to work on chemical stimuli, the investigation of visual stimuli for behavioral manipulation has been much less. This is probably due in large part to the lack of specificity of many visual stimuli involved in behaviors (e.g. image flow during flight), as well as the general impracticality of changing visual stimuli to effect behavior. For example, it is difficult to change the visual properties of plants to make them less attractive to insects, although gibberellic acid has been used to keep grapefruit green and less attractive than yellow fruit to Caribbean fruit fly females. However, visual stimuli are important, if often unrecognized, components of many behavioral manipulation methods, as in the effects of color and form of odor-baited traps in eliciting landing and catch of a pest.

For behavioral manipulation, only two classes of mechanical stimuli warrant mention, **tactile and acoustic**. Tactile stimuli are perceived during contact and are important in the acceptance of hosts, as in the ovipositional behavior of female insects. Difficulties in definition and reproduction have limited their use in behavioral manipulation. In contrast to tactile and other mechanical stimuli, acoustic stimuli can be defined precisely. However, the use of acoustic stimuli is relatively uncommon among insects. Their use in behavioral manipulation is limited to pests that exhibit long-range phonotaxis. Acoustic stimuli, generated naturally or electronically, have been used to attract mole crickets and field crickets and have also been shown to be useful for attracting male mosquitoes of the genus *Anopheles*. To date, the high cost of sound-generating equipment has limited the application of acoustic stimuli to monitoring pest populations.

Although external stimuli are most commonly used, it is sometimes possible to change internal inputs to a behavior, at least at a gross level. For example, mated female insects often receive different mechanical and hormonal internal stimuli that cause them to behave differently than virgin females.

Although defining and reproducing stimuli generally allows greater flexibility and control in behavioral manipulation, it is by no means essential. Undefined or poorly defined stimuli, in the form of natural objects such as plants, frequently are used to manipulate behaviors, an approach that does not require extensive research to define stimuli. The resulting lack of definition, however, also means that there is little control over the stimuli, and if the method does not work, there is little recourse to constructive change.

Manipulation of insect behavior through stimuli must be conducted within the context of a method to be useful. A method consists of a strategy for behavioral manipulation and the mechanism that implements the strategy. For example, in the attract-annihilate method (see below), the strategy is to attract pests to a site and remove them from the environment, and the mechanism may be a trap or a surface coated with a deleterious substance (toxin or pathogen).

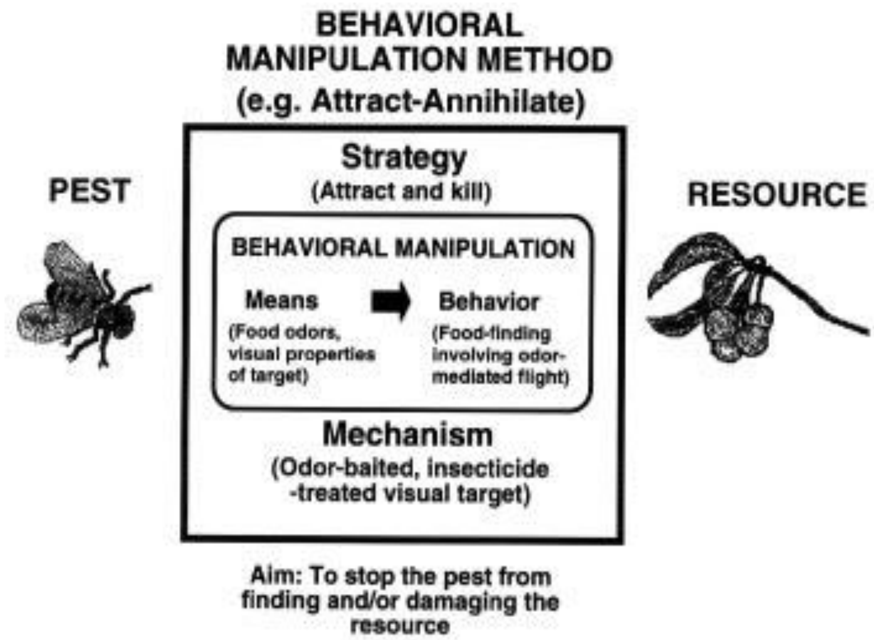

Fig. 12.1: The behavioral manipulation method concept illustrated using the example of an attract-annihilate method.

3.2 Examples of Behavioural Manipulation Methods

In this section behavioral methods that have been used for the control of insect pests are reviewed. The methods have been classified into;

- those that act over a long distance (finding-type behaviors) and
- those that act at a short-distance (acceptance-type behaviors).

To describe the types of stimuli, especially chemicals, the common terms of attractant and repellent for long-distance stimuli and stimulant and deterrent for short-distance stimuli are used.

3.2.1 Stimuli that Act Over Long Distances

3.2.1.1 Attract-Annihilate

The attract-annihilate method is by far the most widely used behavioral manipulation for pest management. The strategy of the method is simple: attract the pests to a site where as many of them as possible can be removed from the environment. The behavioral manipulation involves a long-distance attractant, and the mechanism consists of a device whereby the attracted pests are killed or trapped. This method has been used for many pests whose behavior includes long distance orientation, usually flight but also walking, as in certain species of cockroaches. The most commonly used attractants are volatile chemicals, but visual stimuli are also used (intentionally or incidentally) and auditory stimuli could also be used.

i. Chemical Stimuli

Sex pheromones have been identified for a large number of insect pests, particularly Lepidoptera. These chemicals have a number of useful attributes for the attract-annihilate method, including specificity, eliciting long-distance responses, and longevity in the field. However, because most sex pheromones are produced by females and elicit responses from males, they have been used primarily in the mating disruption method or for monitoring rather than in the attract-annihilate method. Removal of adult males, unless at a very high proportion of the population, is unlikely to have a large impact on the size of subsequent generations compared to removal of females. Nonetheless, there are a few examples of effective control by mass-trapping based on sex pheromones, including the citrus flower moth *Prays citri* on lemons in Israel, sporadic outbreaks of the gypsy moth in the United States, and some stored-product pests in warehouses. Sex pheromones have also been used as attractants to facilitate contact with and dispersal of pathogens in pest populations.

The limitation of a sex pheromone attracting only males can be overcome by combining it with an attractant for females. Theoretically, such a combination should be more effective in the attract-annihilate method than either attractant alone. A combination of the sex pheromone, which attracts males, and a food lure (a mixture of phenethyl propionate, eugenol, and geraniol), which predominantly attracts females, has been used against the Japanese beetle, *Popillia japonica.* The combination trapped more males and females than the two attractants did when used separately. Visual stimuli are also important for *P. japonica*, and the catch of beetles is greater in white traps than those of other colors.

Aggregation pheromones attract both sexes and in some species immatures, e.g. nymphs of the German cockroach *Blatella germanica*. Their ability to attract females makes these pheromones well suited for the attract-annihilate method. Aggregation pheromones have been used successfully for controlling various Coleoptera, including the cotton boll weevil, *Anthonomus grandis*, in the United States and bark beetles in North America and Europe.

The olive fruit fly, *Dacus oleae*, a major pest of olives in the Mediterranean region, has been controlled as effectively as with insecticides by an elaborate mass-trapping method. Females of this species produce a blend of compounds that attracts males over a distance. One of these compounds, 1,7- dioxaspiro[5.5]undecane is also produced by males. The (R)-(−) enantiomer of this compound attracts only males, and the (S)-(C) form of this compound elicits a response that appears to be aggregation by females. The method involves a combination of attractants and stimulants on an insecticide-treated wooden board, which includes a racemic mixture of spiroacetal, a food attractant (ammonium salts) for females, a hygroscopic substance (glycerol) because the flies are attracted to moisture, and a feeding stimulant (sugar) that is used to increase contact with the insecticide.

The screwworm flies *Cochliomyia hominivorax* and *Cochliomyia macellaria* are major pests of livestock in tropical America, and recently *C. macellaria* has also been recognized as a pest in North Africa. These flies, which lay their eggs in wounds, are attracted to carrion, and raw meat (often a combination of liver and sodium sulfide) is used in traps to control or monitor them. A number of the chemicals in rotting meat that attract screwworm flies have been identified and used as an attractant, originally called swormlure, for screwworm control. The most effective formulation, now known as swormlure-4, contains ten components, including butanol, several organic acids, phenol, cresol, indole, and dimethyl disulfide.

In addition to their use in traps, swormlure and its derivatives have been used in two other attract-annihilate methods to control or eradicate screwworms, as well as in the sterile male technique. The screwworm adult suppression system (SWASS) consists of a pelletized formulation containing the chemical lure, food (dried blood), a feeding stimulant (sugar), and an insecticide. This combination attracts the flies and induces them to feed, thereby acquiring a lethal dose of insecticide. The pellets are generally dropped from aircraft.

In the SWASS method, pellets must be dropped twice weekly for effective control because of their short life under field conditions (3–5 days). In addition, although the pellets restrict insecticide usage, they pose a threat to the environment, particularly around waterways and inhabited areas. To overcome these limitations, a protected bait station utilizing the same combination of methods as the SWASS was developed. The longevity of these stations is about 45 to 60 days.

A chemical need not be a natural stimulus in a behavior to function as an attractant. Many so-called moth sex attractants, which attract male moths but have not been identified in conspecific females, have been found by screening large numbers of related chemicals. A group of chemicals that has proven very effective as attractants for certain species of tephritid flies are the male lures. The most important of these chemicals are methyl eugenol, 1-(p-acetoxyphenyl)-butan-3-one (cue-lure), and t-butyl 4 (or 5)-chloro-2-methyl-cyclohexanoate (trimedlure), which attract males of various species of Tephritidae of the Old World tropics and subtropics and Oceania. Despite a great deal of investigation, these chemicals have no known role in the natural biology of the flies, yet they elicit much greater responses than any natural sex pheromone in the respective species of flies.

Methyl eugenol was first used in a male eradication program for the Oriental fruit fly, *Dacus dorsalis*, by Steiner and coworkers on the island of Rota (north of Guam) in the Marianas. Essentially, they absorbed a mixture of methyl eugenol and insecticide (naled) onto cane-fibre squares and either threw them out of an airplane in uninhabited areas or placed them in trees in village areas. This method, either alone or in combination with another such as the sterile male technique, subsequently has been used a number of times to control or eradicate populations of Oriental fruit fly in the Marianas, the United States, and Japan. It also was used to eradicate an infestation of *Dacus zonatus* in California in 1987.

Food baits are also useful for monitoring or controlling tephritids. Probably the most important of these have been the protein hydrolysates of corn, soybeans, or yeast. Microbial fermentation of these baits produces volatile chemicals that attract a range of tephritids. They have the advantage over male lures of attracting females as well as males (28). Protein-hydrolysate-baited toxic baits have been used to eradicate the Mediterranean fruit fly, *Ceratitis capitata*, in the mainland United States during the later part of this century.

ii. Visual Stimuli

Visual stimuli alone are much less commonly used in attract-annihilate methods than chemical stimuli. Many hemipterans as well as species in other orders are attracted to light in the green-yellow region of the spectrum. This attraction has been utilized in the development of yellow sticky traps for monitoring a number of pests, including the citrus blackfly, *Aleurocanthus woglumi*); the tarnished plant bug, *Lygus lineolaris*; the beet leafhopper, *Circulifer tenellus*; and the greenhouse whitefly, *Trialeurodes vaporariorum*, in commercial orchards or greenhouses.

Samways attempted to use attraction to green-yellowlight to develop an attract-annihilate method for the citrus psylla, *Trioza erytrae*, a vector of citrus greening disease in southern Africa. The method consisted of a combination of perimeter sticky traps, utilizing a plastic sheet with high reflectance in the yellow region and low reflectance in the blue, and pesticide-treated trap trees. Although fewer insects were caught inside the protected area than outside, there was no significant difference between mean population levels over the period of the experiment. In part, this was due to the very low population numbers of the pest during the trial, as shownby trap catches, and also perhaps because of conditions that suppressed dispersal. This method needs to be tested more rigorously, under different environmental conditions and at different population levels, in order to determine its suitability for control of this and perhaps other pests.

Visual and Chemical Stimuli

Visual stimuli are used most frequently in combination with chemical stimuli, enhancing the efficacy of a method over the use of either stimulus type alone. Even in methods that do not purport to use visual stimuli, such as sex pheromone-baited traps, the visual stimuli of traps are important. Tsetse (*Glossina* spp.), which are the vectors of the protozoans that cause trypanosomiases in sub-Saharan Africa, including human sleeping sickness and important animal diseases, provide one of the best examples of the use of both visual and chemical stimuli in an attract-annihilate method. Attract-annihilate methods are particularly suitable for control of tsetse because of the adenotrophic viviparity and low reproductive potential of each female, which commonly produces less than ten offspring. The host-finding behavior of tsetse is influenced by visual stimuli, including shape, orientation, brightness, contrast, movement, and color. Traps using only visual stimuli, such as the biconical trap, are used for control of these flies. Tsetse also respond to host odors, some of the attractive components of which include CO_2, 1-octen-3-ol, butanone, acetone, and various phenols. The addition of odor (acetone and CO_2) to the biconical trap doubled catches over a non-odor-baited trap.

In recent years, control of tsetse has relied increasingly on the use of odor baited black cloth targets coated with insecticide. The combination of visual and olfactory stimuli appears to concentrate a fly's movements toward the target, as well as to increase its chances of landing on it. Recently, the efficacy of odor-baited tree stumps with a nearby insecticide-treated netting was investigated for tsetse control; the method was effective with short trunks but less so with taller, upright trunks, which tsetse avoid. An attract-annihilate target method utilizing both chemical and visual stimuli similar to that used for tsetse flies is being developed for screwworm control.

An elegant variant of the attract-annihilate method has been devised for control of the apple maggot fly, *Rhagoletis pomonella*. Females of this species find host trees and suitable oviposition sites on apples using a combination of host odors and visual stimuli. Initially, a sticky red wooden sphere (slightly larger than an apple) was developed for the control of this fly. Hanging these sticky spheres on each tree in an apple orchard gave good protection (<1% damage) of fruit from *R. pomonella*. The trap was improved through identification of odors from apples that attract the flies. Placing the sticky spheres baited with butyl hexanoate on the perimeter trees of a small orchard block gave protection equal to that of non-baited spheres on every tree of the block. Principally because of difficulties with handling the sticky spheres and the need to recoat them regularly to maintain efficacy, a pesticide-coated target was developed. In addition to the combination of odor and visual stimuli the red spheres are coated with a feeding stimulant (corn syrup), which increases contact of the flies with the insecticide; without the feeding stimulant, most of the flies do not remain on the sphere for sufficient time to be exposed to a lethal dose of insecticide. The targets are as effective as sticky spheres as long as they are dipped in sugar solution after each rainfall.

3.2.1.2 Disrupting Behavior Using Attractants and Repellents

Disrupting behavior with stimuli that either elicit or inhibit orientation is also effective at long distances. In practice, only attractant and repellent chemicals have been used. The distinction between attractants and repellents is less clear than the names suggest. Most stimuli that attract will repel at higher concentrations. Stimuli that repel a pest may elicit orientation in the same or other species. For example, the insect repellent N,N-diethyl-m-toluamide (deet) will attract the mosquito *Aedes aegypti* at sufficiently low concentrations. These terms, particularly “repellent,” are often used problematically in the literature, because the actual effect of the chemical is surmised from the end result of the behavior, which could be influenced by short-range stimuli such as deterrents. Nevertheless, attractants or repellents are generally identified as such in behavioral manipulation methods, and we follow conventional usage.

i. Attractants

Most work on the use of attractants to disrupt a finding behavior has focused on mate location, particularly of moths, in the so-called mating disruption method. Large amounts of synthetic sex pheromone are distributed with the aim of preventing males from finding females. This method has been used successfully for control of such herbivorous pests as the pink bollworm, *Pectinophora gossypiella*, on cotton; the Oriental fruit moth, *Grapholita molesta*, on stone fruits; the tomato pinworm, *Keiferia lycopersicella*, on tomatoes; and the currant clearwing, *Synanthedon tipuliformis*, on blackcurrants. In virtually all cases where the method has been attempted, disruption of mating has been at least partially achieved in the treated area. However, the success of the method for management of a given pest depends to a large extent on its biology and particularly on the potential for immigration of mated females from outside the
treated area.

A number of possible behavioral modes of action have been suggested for mating disruption with synthetic pheromones, including diminution of response due to sensory adaptation or habituation, arrestment of upwind flight at high concentrations, shifting the rhythm of response to females, changing the fine structure of or camouflaging a natural plume, outcompeting females, and causing an imbalance of sensory inputs by altering the perceived blend. In spite of the large amount of work on mating disruption of moths, as well as the considerable volume of work on the actual behavioral mechanisms used by male moths in response to pheromone, "the extent to which any of these mechanisms actually participate in achieving mating disruption remains speculative, because either direct field experimentations have failed to explore all the mechanisms or, more likely, such tests have not been attempted".

An interesting variant of the mating disruption method is used for control of the pink bollworm in California: an insecticide, permethrin, is added to the sticker used to attach the pheromone formulation to the leaves of the plant. This combination is thought to increase the control of bollworm over the pheromone alone.

Another example of an attractant used to disrupt a finding behavior has been provided by the navel orangeworm, *Amyelois transitella*, a pest of almonds in California. Both volatile chemicals emanating from almond fruits and frass of larvae feeding on almonds stimulate oviposition by female navel orangeworm and provide an effective attractant in monitoring traps. Chemicals from almond oil elicit upwind flight over relatively long distances (>2 m). Spraying a formulation of 5% crude almond oil in water on almond trees suppressed egg deposition on egg traps and reduced the infestation of mummy nuts (unharvested, previous year's nuts) in a California orchard. Although the behavioral mode of action that led to the decrease of oviposition was not determined, the volatility of the active component(s) suggests that the method disrupted the orientation and finding behavior of the females. Almond oil in combination with an insecticide also shows promise as an attract-annihilate method for the navel orangeworm.

ii. Repellents

The strategy for using repellents is, generally, to stop a pest from finding a valued resource. Useful repellents can be derived from natural sources such as insects (e.g. defense secretions), or they may be purely artificial as in the case of most insecticides. Most work on the practical use of volatile repellents has been to protect humans from insect bites, particularly from those insects such as mosquitoes and blackflies that are vectors of diseases. Of these chemicals, the best known is deet, which is used as a repellent for a wide range of insects.

Repellents to protect crops, except those also with general insecticidal activity such as nicotine, have received little attention in contrast to the great amount of investigation into the chemical basis of plant resistance against insects. Verbenone, a known inhibitor of aggregation in bark beetles, and pine oil repel colonization of forest trees or logs by various species of bark beetles. Interestingly, pine oil has also been used in the laboratory to prevent oviposition by the onion fly, *Delia antiqua*, on treated onion halves, although the behavioral mode of action (repellency or deterrency) was not determined. Another repellent that has been used to protect a plant resource is the chemical (*E*)-(β)-farnesene, a major component of alarm pheromones of a number of species of aphids. Laboratory and field trials showed that this compound increased contact with toxic chemicals and fungal pathogens by the aphid *Myzus persicae*

3.2.2 Stimuli Acting at Close Distance

After arriving at a resource, an insect is likely to contact additional (to those perceived at greater distances) stimuli. These stimuli can either stimulate a behavior, keeping the insect at the resource, or inhibit that behavior, resulting in rejection of and possibly movement away from the resource. Virtually all the short-range stimuli used in behavioral manipulation are chemicals.

3.2.2.1 Stimulants

Most known stimulants are involved in either feeding or oviposition, primarily the former. Advantages of stimulants include increasing exposure to toxins that must be ingested and applicability to a wide range of pests, as in the case of sucrose. Feeding stimulants also are often common carbohydrates, proteins, or fats that are easily obtained and relatively inexpensive, whereas oviposition stimulants can be highly specific, even among pests that threaten same resource, and expensive.

Feeding stimulants are especially useful in conjunction with toxins, because they can increase contact that may be suppressed if the pest responds to the toxin by ceasing to feed, thus avoiding a lethal dose (e.g. endotoxins of *Bacillus thuringiensis*). They also have been used in combination with attractants (attract-annihilate method) using commercially available stimulants, e.g. protein hydrolysate in the eradication of tephritid fruit flies and sugars for control of flies around animal rearing facilities.

Other feeding stimulants in development for use in toxic baits are the cucurbitacins. These oxygenated tetracyclic triterpenoids found in many species of Cucurbitaceae stimulate compulsive feeding in adults of a number of species of diabroticite beetles, including corn rootworms, *Diabrotica* spp., which are important pests in the United States. Cucurbitacins are obtained by growing plants with high concentrations and harvesting, drying, and grinding them to a powder that is combined with an insecticide as bait. In small trials, such baits have been effective in reducing populations of several species of corn rootworms. Because cucurbitacins act only as feeding stimulants, chemical attractants have been sought to increase the number of rootworms finding the baits. Rootworm attractants appear to be more species-specific than the feeding stimulants but have improved the efficacy of poison baits in some studies.

Oviposition stimulants have not yet been used commercially for pest control, but such a method is suggested by the work of Unnithan & Saxena. In this study, oviposition by the sorghum shootfly was stimulated on nonhost plants (corn) by applying an acetone extract of sorghum. In small field trials, the extract diverted oviposition from the sorghum. Although this effect was attributed to an oviposition stimulant, it may have acted as contact stimulant, a long-distance attractant, or both.

3.2.2.2 Deterrents

A deterrent is a chemical that inhibits behavior, such as feeding or oviposition, when applied to a site where such behavior normally occurs. In pest management, a deterrent is applied directly to a resource to prevent or reduce the effects of a pestilential behavior such as feeding. Efficacy depends on the physiological state and behavioral responses of the pest during initial and subsequent encounters with the deterrent. If a pest stays on or returns to the resource, protection may break down in several ways, of which the most important is desensitization. Numerous pest insects have been shown to lose their responsiveness to deterrents after repeated exposure and after increasingly long periods of deprivation of feeding or ovipositional sites.

Protection also may break down when the resource is not uniformly treated with the deterrent, and the pest can move to an untreated part. For examples, plants can grow after a deterrent has been applied and therefore present the pest with unprotected surfaces over time, except in the case of systemic deterrents. However, movement of a pest from a deterrent-treated site to a deterrent free site can be exploited for pest management if the movement brings the pest to a non valued part of the resource or an area that has been treated with a pesticide. This strategy was used against larvae of the mustard beetle, *Phaedron cochliereae*, which were deterred from feeding by application of extracts of plants in the genus *Ajuga* to the young leaves at the top of mustard plants; beetles moving down to feed on older leaves were controlled by an insect growth regulator.

Because deterrents repress behaviors, oviposition or feeding deterrents are often found by studying the chemistry of plants on which pests do not feed or oviposit. Many researchers see deterrents as more important in host plant preferences than stimulants. Frass of species other than the target that feed on similar host plants are another potential source of deterrents. The cabbage root fly, *Delia radicum*, did not lay eggs on cauliflower plants sprayed with an extract of the frass of caterpillars of the garden pebble moth, with sinapic acid as the active component.

Deterrents found in extracts of the Neem tree have attracted great interest in recent years, especially azadirachtin. Neem extracts and azadirachtin affect behavior, growth regulation, ovarian development, fecundity, and fertility in insects. Neem chemicals may control pests that will not consume them by deterrent effects. Lepidoptera are most sensitive to azadirachtin, with feeding deterred at <1–50 ppm. The dual action of deterrence and toxicity and the many pest species that are controlled by one or both of these actions contribute to interest in Neem chemicals.

Only a few plant-derived feeding deterrents in addition to Neem have been tested in small glasshouse or field plots. Polygodial, a plant-derived dialdehydic sesquiterpenoid in the drimane series, is a feeding deterrent for various lepidopteran pests such as *Spodoptera* and *Heliothis* species and for the aphid *M. persicae*. In *M. persicae*, deterrence of feeding decreased spread of persistent and semipersistent plant viruses. In field trials, polygodial significantly reduced transmission of barley yellow dwarf virus by the aphid *Rhopalosiphum padi* and increased yields of barley from 3.83 to 5.22 tonnes per hectare. Fatty acids, such as dodecanoic acid and plant-derived oils, are also under examination as feeding deterrents against aphids and have shown some promise in small trials.

The deterrent properties of fungicides have been known for many decades and were discovered through observations of pest populations feeding on treated and untreated plants. When organotin and copper compounds used as fungicides to protect potatoes against disease were replaced with systemic fungicides, populations of Colorado potato beetle increased substantially.

The fungicides were subsequently shown to control beetle populations by deterring feeding. When sprayed on crops in field trials, these compounds have successfully controlled various species of Lepidoptera, Coleoptera, and Hymenoptera. Despite their success in pest management, organotins fell from favor in the late 1970s because of environmental concerns. Copper fungicides are still used as feeding deterrents and have been proposed for managing pesticide resistance in Colorado potato beetles.

Field trials on oviposition deterrents are limited to a single species, the cherry fruit fly, *Rhagoletis cerasi*. A host-marking pheromone put on the fruit by the female after she oviposits deters oviposition by conspecifics on the same fruit. An extract of the pheromone sprayed on cherry trees reduced fruit infestation by wild *R. cerasi* larvae tenfold. Trials with the synthetic pheromone have given similar reductions in fruit infestation. The recent identification and synthesis of host-marking pheromones from the eggs of butterflies in the genus *Pieris* and the relative stability of these compounds present a similar opportunity for using oviposition deterrents to protect cabbage crops from these pests.

Combining Deterrents and Attractants/Stimulants

Several authors have suggested that the efficacy of a deterrent-based method may be increased if used in combination with another method that attracts the pest to a non-valued resource in a stimulo-deterrent diversion or push-pull strategy. The combination of methods might overcome such difficulties with deterrents as desensitization and untreated areas of the resource.

The stimulo-deterrent strategy (SDD) was conceived for insect herbivores but is applicable to any pest and any resource type. To date, it has only been tested against a small number of herbivores in small field or glasshouse trials and has yet to be used commercially. The onion fly *D. antiqua* can be deterred from laying eggs on seedling onions by cinnamaldehyde and stimulated to lay eggs on worthless cull onion bulbs that are planted in the same field. In large-scale field trials using microencapsulated cinnamaldehyde as the deterrent and cull onions as the stimulant, the SDD strategy appeared to give good protection for the first few weeks following application. Control subsequently broke down due to the short lifespan of the deterrent formulation. Moths of the genus *Heliothis* were deterred from ovipositing on cotton by azadirachtin and stimulated to oviposit on pigeon pea or maize crops. Although the two methods have not yet been combined, researchers in Britain have shown in separate field trials that the adult pea and bean weevil, *Sitona lineatus*, can be deterred from feeding on a leguminous crop by neem oil and attracted into other crop fields using aggregation pheromones. As suitable deterrents and stimulants are identified, it seems likely that such combined behavioral manipulation methods will be developed for a wider range of pests and resources.

Internal Stimuli

One exception to the generalization that internal stimuli are inaccessible for manipulating behavior is the sterile male technique, in which large numbers of sterile males are released to mate with wild females. The mating induces many of the same internal inputs in the females as in those mated to normal, fertile males. These internal inputs induce a number of behavioral changes in the female. Most usefully, the female becomes refractory to further matings, and in species in which the female mates only once, will remain refractory permanently and hence never be fertilized.

The sterile male technique has been used successfully in eradication programs, usually in combination with other methods such as poison baits, against isolated or incipient populations of economically severe pests where the risk of reintroduction is low, such as the primary screwworm in North and Central America and various tephritid fruit flies. The method can be used for control through ongoing population suppression, but the high cost of producing the large numbers of high-quality insects needed to swamp or outcompete wild males generally makes this approach uneconomical. Besides a large rearing program producing high-quality insects, the method requires an ability to sterilize large numbers of insects (usually by X-ray or γ-ray exposure), and an effective monitoring system that can be used to detect the pests and to estimate the size of the pest population.

4.0 CONCLUSION

Behavioral manipulation methods for pest management can be developed in a variety of ways, from detailed studies of behavior in the laboratory and field (e.g. apple maggot fly) to nearly serendipitous observations of pest populations in the field (e.g. effects of fungicides on Colorado potato beetle). However, without a thorough understanding of the behavior and ecology of the pest, the chances for developing a successful method other than by serendipity are slight, and the ability to modify and refine the method to enhance its efficacy for pest management is limited.

The behavior of insects is influenced by many stimuli, both external and internal and failure to account for the effects of these stimuli may result in apparent variable results with a behavioral manipulation. Internal stimuli related to different physiological and experiential states are important sources of behavioral variability and should not be ignored. The examples of the excellent studies on tsetse and other flies testify to the benefits of identifying and using multiple types of stimuli in behavioral manipulation for pest management.

Understanding the range of behaviors exhibited by a pest throughout its life cycle assists identification of those most suitable for manipulation, as well as allowing one to develop elaborate combinations of behavioral manipulations. Examples of these more elaborate methods include combinations of distinct behaviors with a common behavioral mechanism, e.g. sex pheromone and food odors in traps for the Japanese beetle; combinations of complementary behaviors, e.g. the attractant and feeding stimulant used in toxic baits for olive fruit fly; and combinations of converse behaviors, e.g. the stimulo-deterrent diversion strategy for herbivores.

There have been a limited number of successful examples of behavioral manipulation methods in pest management. Whether these and new behavioral manipulation methods continue to occupy a relatively small niche or play a major role in pest management is likely to depend on the amount of research on the causes of insect behavior and the development of creative methods for utilizing the results of this research.

5.0 SUMMARY

Behavioural manipulation is defined as the use of stimuli that either stimulate or inhibit a behaviour and thereby change its expression. The principal elements of a behavioural manipulation are; behaviour of the pest, means by which the behaviour is manipulated appropriately and a method that utilizes the behavioural manipulation for protection of a resource from the pest. The choice of a stimulus to use is usually dependent upon attributes such as; accessibility, controllability, specificity, etc. Behavioural methods that have used for the control of insect pests are classified into; those that act over a long distance (finding-type behaviours) and those that act at a short distance (acceptance-type behaviours).

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. what do you understand by the term 'behavioural manipulation'.
2. What are the principal elements of a behavioural manipulation method
3. Describe finding-type behaviours
4. Explain the attributes that the choice of a stimulus to use are dependent upon
5. Give examples of stimuli that act at a short distance
6. How can behavioural manipulation be utilized in pest management

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MODULE 4

UNIT 1: ALTERNATIVE CONTROL STRATEGIES: SEMIO-CHEMICALS

CONTENTS

1.0 INTRODUCTION

In this unit, the various classes of semio-chemicals and their uses are discussed.

2.0 OBJECTIVES

At the end of this unit, you should be able to;

- Define the term semio-chemicals
- State the goals of using them
- Describe the various classes of semio-chemicals and their use

3.0 MAIN CONTENT

3.1 Background and Goals of using Semio-chemicals

Primary metabolic processes in plants produce substances to catalyze reactions, build tissues and supply energy. The plant requires inorganic ions and produces enzymes, hormones, carbohydrates, lipids, proteins and phosphorus compounds for energy transfer. Together, these primary metabolites promote growth and reproduction of the plant. For insects, some of these primary metabolites are feeding stimulants, nutrients and toxicants. Other primary metabolites are inert as far as an insect is concerned.

Secondary metabolic processes in plants seem to be coincidental to primary metabolism. The chemicals produced, secondary metabolites, vary widely among plants and are believed nonessential in primary metabolism. Some of these secondary metabolites are thought to have arisen as mechanisms of chemical defense against plant eating. They may be stored in any convenient place in the plant structure and often are exuded from outer layers of plant tissues. Here, they may be sensed by insects and function as token stimuli. A token stimulus elicits response initially and afterward has no effect.

This relationship between plant chemical stimuli and insect response is a form of chemical communication between these organisms. Such chemicals are called Semiochemicals. They are chemical substances that mediate communication between organisms.

The **goals** of using semio-chemicals in pest management are ;

1. to monitor pest populations to determine if control is warranted and
2. to alter the behavior of the pest or its enemies to the detriment of the pest.

In general, the **advantages** of using semiochemicals are ;

1. they have adverse effects only on target pests,
2. they are relatively nontoxic and required in low amounts,
3. they are nonpersistent and environmentally safe
4. they appear difficult for insects to develop resistance against. Monitoring of pest populations with pheromones is often integrated in management programs.

3.2 Classification of Semio-Chemicals

Semiochemicals maybe classified into Pheromones (intraspecific semiochemicals) and Allelochemics (interspecific semiochemicals).

3.2.1 Pheromones

Pheromones are chemicals secreted into the external environment by an animal which elicit a specific reaction in a receiving individual of the same species. They promote communication between members of the same species. Pheromones are volatile in nature and they aid in communication among insects.

Pheromones are exocrine in origin (i.e. secreted outside the body). Hence they were earlier called as **ectohormones**. In 1959, German chemists, Karlson and Butenandt isolated and identified the first pheromone, a sex attractant from silkworm moths. They coined the term pheromone. Since this first report, hundreds of pheromones have been identified in many organisms. The advancement made in analytical chemistry aided pheromone research.

Based on the responses elicited, pheromones can be classified into 2 groups;

3.2.1.1 Primer pheromones:

They trigger off a chain of physiological changes in the recipient without any immediate change in the behaviour. They act through gustatory (taste) sensilla. (e.g.) Caste determination and reproduction in social insects like ants, bees, wasps, and termites are mediated by primer pheromones. These pheromones are not of much practical value in IPM.

3.2.1.2 Releaser pheromones:

These pheromones produce an immediate change in the behaviour of the recipient. They act through olfactory (smell) sensilla and directly act on the central nervous system of the recipient and modify their behaviour. They can be successfully used in pest management programmes.

Releaser pheromones may be further subdivided based on their biological activity into:

3.2.1.2.1 Sex pheromones:

They are released by one sex only and trigger behaviour patterns in the other sex that facilitate mating. These substances are often produced by females to attract males for mating, but they may also be produced by males to attract females. They seem to be the most highly developed in Lepidoptera and are frequently produced by eversible glands at the tip of the abdomen. The release of sex pheromones is a complex physiological process, often associated with sexual maturity and environmental stimuli such as; photoperiod and light intensity. Female sex pheromones are usually received by sensory sensillae on male antennae, and males search upwind, following the odour corridor of the female.

Major differences between male and female produced pheromones are listed below.

Sl. No	Properies	Female sex pheromone	Male sex pheromone
1.	Range	Acts at a long range. Attracts males from long distance	Acts at a short distance
2	Role of other stimuli	Play less role	Visual and auduitory stimuli play major role
3.	Action elicited in the other sex	Atrracts and excites males to copulate	Lowers females resistance to mating
4.	Importance in IPM	More important	Less important

Insect orders producing sex pheromones :

Lepidoptera, Orthoptera, Dictyoptera, Diptera, Coleoptera, Hymenoptera, Hemiptera, Neuroptera and mecoptera. In Lepidoptera, sex pheromonal system is highly evolved.

Pheromone producing glands*:*

In Lepidoptera, they are produced by **eversible glands** at the tip of the abdomen of the females. The posture shown during pheromone release is called 'calling position'. Aphrodisiac glands of male insects are present as **scent brushes** (or hair pencils) at the tip of the abdomen (e.g. Male butterfly of *Danaus sp.*). **Andraconia** are glandular scales on wings of male moths producing aphrodisiacs.

Pheromone reception:

Female sex pheromones are usually received by olfactory sensillae on male antennae and males search upwind, following the odour corridor of the females. In pheromone perceiving insects, the antennae of male moths are larger and greatly branched than female moths to accommodate numerous olfactory sensilla.

Chemical nature of sex pheromones

In general pheromones have a large number of carbon atoms (10-20) and high molecular weight (180 – 300 daltons). Narrow specificity and high potency are two attributes which depend on long chain carbon atoms and high molecular weight. But since pheromones are volatile their molecular weights cannot be very high as they cannot be carried by wind.

Butenandt and his coworkers in 1959 isolated 12mg of pheromone from the abdomen of half a million virgin females of silkworm. They named the pheromene as Bombykol. The chemical name is 10,12 – hexadeca dienol. It is a primary alcohol.

The following are some of the female sex pheromones identified in insects

Sl. No.	Name of the Insect	Pheromone
1.	Silkworm, *Bombyx mori*	Bombykol
2.	Gypsy moth, *Porthesia dispar*	Gyplure, disparlure
3.	Pink bollworm ,*Pectinophora gossypiella*	Gossyplure
4.	Cabbage looper, *Trichoplusia ni*	Looplure
5.	Tobacco cutworm, *Spodoptera litura*	Spodolure, litlure
6.	Gram pod borer, *Helicoverpa armigera*	Helilure
7.	Honey bee queen, *Apis sp.*	Queen's substance

Examples of male sex pheromones

- Cotton boll weevil, *Anthonomas grandis*, Coleoptera
- Cabbage looper, *Trichoplusia ni*, Lepidoptera
- Mediterranean fruitfly, *Ceratitis capitata*, Diptera.

Multi-component pheromone system : If the pheromone of an insect is composed of only one chemical compound we call it monocomponent pheromone system. Pheromones of some insects contain more than one chemical compound. In this case we call it a multi-component pheromone system. The sex pheromone of two different species may contain same chemical compounds but the ratio of the compounds may vary. This brings about species specificity.

Pest Management with Sex Pheromones

Synthetic analogues of sex pheromones of quite a large number of pests are now available for use in Pest management. Sex pheromones are being used in pest management in three different ways.

a) In sampling and detection (Monitoring)

b) To attract and kill (Mass trapping)

c) To disrupt mating (Confusion or Decoy method)

3.2.1.2.2 Alarm Pheromones:

These pheromones are common in social insects such as ants and bees. They elicit attack or retreat behavior. For instance, the remains of a sting apparatus of a honey bee left in a victim's body releases an alarm pheromone that attracts other bees and stimulates them to sting.

3.2.1.2.3 Trail-marking Pheromones:

These chemicals are produced by foraging ants an termites to indicate cources of requisites to other members of the colony.

3.2.1.2.4 Aggregation Pheromones:

These pheromones are prominent in some species of beetles and cause insects to aggregate or congregate at food sites, reproductive habits, hibernation sites and the like. They are particularly well known in bark beetles, *Ips* species and *Dendroctonus* species, where they are involved in tree attacks.

3.2.1.2.5 Epideictic Pheromones:

Also called Spacing Pheromones. They elicit dispersal away from potentially crowded food sources, thereby reducing numbers. Hence, they are one of the few pheromones that serve to repel rather than attract. They are produced by bark beetles, as well as other Coleoptera, Lepidoptera, Diptera, Homoptera, Orthoptera and Hymenoptera.

3.2.2 Allelochemics

These promote communication between members of different species. They can be subdivided further into Allomones and Kairomones.

3.2.2.1 Allomones

They are chemical substances produced and released by an individual of one species that affects the behaviour of a member of another species to the benefit of the originator but not the receiver. They are mostly defensive chemicals producing negative responses in insects and reducing chances of contact and utilization. Production of allomones is a common form of defence, particularly by plant species against insect herbivores. They include repellents, oviposition and feeding deterrents and toxicants.

3.2.2.2 Kairomones

They are semiochemicals emitted by an organism, which mediates interspecific interactions in a way that benefits an individual of another species which receives it, without benefitting the emitter. They are advantageous to an insect promoting host finding, oviposition and feeding. They include: attractants, arrestants, excitants and stimulants. Two main ecological cues are provided by kairomones; they generally either indicate a food source for the receiver, or give warning of the presence of a predator.

4.0 CONCLUSION

The term semio-chemicals, its background, classes, advantages and examples have been treated in this unit.

5.0 SUMMARY

Semio-chemicals are chemicals that mediate communication between organisms. They are classified into pheromones and allelochemics. Pheromones are further divided into primer pheromones and releaser pheromones. The releaser pheromones are subdivided into sex pheromones, aggregation pheromones, alarm pheromones, etc. sex pheromones are used in IPM. Allelochemics are divided into allomones and kairomones

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. What do you understand by the term semio-chemicals?

2. Give a background to the use of semio-chemicals

3. What are the goals and advantages of using semio-chemicals?

4. Define pheromones

5. Which class of pheromenones are most common and why?

6. Differentiate between male and female sex pheromones

7. Mention examples of male and female sex pheromones in named insects

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UNIT 2: ALTERNATIVE CONTROL STRATEGIES: STERILE-INSECT TECHNIQUE

1.0 INTRODUCTION

In this unit, the theoretical background to the use of SIT, examples of sterile-release programmes, the requirements and drawbacks of SIT will be discussed.

2.0 OBJECTIVES

At the end of this unit, you should be able to;

- Define the term sterile-insect technique
- Explain the theoretical background to the use of SIT

- Describe the methods of sterilization
- State the requirements of sterile-release programmes
- Mention the drawbacks of the programme

3.0 MAIN CONTENT

3.1 Definition of Sterile-Insect Technique

The use of sterilized insects and manipulations of pest genetics have developed gradually since about 1916. These tactics are pest-selective, aimed mostly at reducing insect populations by lowering reproductive potentials and they include some of the most innovative and unusual procedures in insect pest technology. Pest insects are used against members of their own species to reduce population levels which is a type of autocidal control called SIT, the sterile-insect technique.

SIT received major input and support from the work of E. F. Knipling, a USDA entomologist in the late 1930s. In the 1950s, R. Bushland began it as a strategy of replacing normal matings in a population with infertile ones in effect inducing sterility. Fundamentally, the sterility principle aims at flooding a population with sterile mates, which seek out and mate with normal females. Such matings result in inviable (unfertlized) eggs, and with continued sterile male releases, the population declines. As decline occurs, the ratio of sterile to normal male increases until virtually no normal males remain. At this point, the population becomes extinct for lack of progeny. Consequently, in most instances, the main objective of SIT has been eradication, not merely suppression as in insect pest management.

Sterility method - Definition

Control of pest population achieved by releasing large number of sterilized male insects, which will compete with the normal males and reduce the insect population in subsequent generation.

It is usually referred to as SIT (Sterile insect technique) or SIRM (Sterile insect release method). Sterile insect release method is a genetic control method. This is also called **Autocidal control** since insects are used against members of their own species.

The sterile-insect technique developed out of studies of the screw-worm fly (*Cochliomyia hominivorax*), a parasite of cattle primarily in tropical and subterranean regions of the New World. Knipling and coworkers noted that adult females mated only once (were monogamous) to fertilize their eggs. Using this knowledge, these workers postulated that if males could be sterilized without impairing their mating behavior, releases into the wild population would result in infertile matings and isolated populations could be eliminated.

Fig. 14.1: Screwworm was the first pest successfully eliminated from an area through the **sterile insect technique** by the use of an area-wide approach

Consequently, there have also been many successes in controlling species of fruit flies, most particularly the Medfly (*Ceratitis capitata*), and the Mexican fruit fly (*Anastrepha ludens*). Also, Tsetse fly eradicated from Zanzibar, Melon fly (*Bactrocera cucurbitae*, Coquillett) eradicated from Okinawa, Japan.

3.2 SIT Theoretical Background

The theory behind the SIT approach can be illustrated by a number of simple models such as tables developed by Knipling to show the behavior of population numbers alone and when subjected to sterile-insect releases. In these models, a hypothetical population, having 1:1 (female to male sex ratio and growing five-fold each generation, is convenient for presentation. This exponentially growing population is shown in Table 1. (This simplistic pattern is not prevalent in the environment because of density-dependent factors and randomly operating density-independent factors. It is used here for explanatory purposes)).

Table 14.1: Trend of a Hypothetical Population with Each Female Producing Five Female Offspring Each generation (Sex Ratio 1:1)

Generation	*Number of Females Per Unit Area*	*Total Number in Population*
1	1,000,000	2,000,000
2	5,000,000	10,000,000
3	25,000,000	50,000,000
4	125,000,000	250,000,000
5	625,000, 000	1,250,000,000

If the same population is subjected to releases of 9 million sterile males each generation as shown in Table 2, numbers are essentially eliminated (eradicated) after the fifth generation. The reason for eradication is that every time a sterile male mates with a female, she is prevented from laying fertile eggs. Therefore, in generation 1, only 10 percent (100,000) of the 1 million females mated with a normal male and even though these females increased their numbers five fold, the population still began a downward trend. Continued inundations of the same number of sterile males caused increasing rates of decline because of increases in the sterile-to-normal-male ratio. In other words, the reproductive penalty (genetic load of numbers dropped. As they dropped, the method increased in effectiveness.

Table 14.2: Trend of the Hypothetical Population Subjected to Sterile-Insect Releases

Gene-ration	*No. of Females Without Releases*	*No. of Sterile Males Released*	*No. of Females with releases (Ratio 9:1)*	*Ratio of Sterile to Normal Males*	*No. of Fertile Females*
1	1,000,000	9,000,000	1,000,000	9:1	100,000
2	5,000,000	9,000,000	500,000	18:1	26,316
3	25,000,000	9,000,000	131,579	68:1	1,907
4	125,000,000	9,000,000	9,535	944:1	10
5	625,000, 000	9,000,000	50	180,000:1	0

A primary principle of the sterile-insect technique is shown from this simple example: the initial number of sterile releases must be great enough to overcome reproduction and start a downward trend in the population. The higher the initial sterile-to-normal male ratio, the quicker the pest eradication. Had only 4 million sterile males been released each generation in the example, the population would still have grown, the method would have become les effective with time and the pest would not be eliminated. Theoretically, the initial ratio of sterile-to-normal males must be greater than the pest's net increase potential from generation to generation to be effective. In other words, if the population is increasing by a factor of five each generation, the ratio would have to be greater than 5:1 for effectiveness. In practice however, the ratio may need to be double the increase factor to compensate for environmental and genetic factors.

The value of the sterile-insect technique can be viewed, at least theoretically, by comparing the hypothetical example with management using anther tactic, insecticide applications. Let us assume that an insecticide is applied each generation to a pest population causing a 90 percent reduction in numbers. The results shown in Table 3, indicate that even though numbers are reduced by the insecticide, a residual population still remains after generation five. If applications are suspended at that time, we would assume the pest population would rebound. On the other hand, the population would be completely eliminated with the sterile-insect technique and the program could be terminated.

Table 14.3: Trend of the Hypothetical Population When Sterile Releases Are Compared with an insecticide Treatment

Generation	*No. of Females With No Treatment*	*No. of Females with releases (Ratio 9:1)*	*No. of Females With Insecticide – 90% Kill*
1	1,000,000	1,000,000	1,000,000
2	5,000,000	500,000	500,000
3	25,000,000	131,579	250,000
4	125,000,000	9,535	125,000
5	625,000, 000	50	62,500
6	3,125,000,000	0	31,250

An important principle from this example is that tactics such as insecticide applications tend to become less efficient as numbers are reduced, whereas the sterile-insect technique becomes more efficient with small numbers. Conversely, when pest populations are large, insecticides are most efficient. Therefore, an effective tactic is to integrate insecticide applications with sterile-male releases in eradication programmes. In this tactic, an insecticide should be applied to cause initial number reduction, followed by successive sterile-male releases. As Table 4 shows, pest numbers with this integrated approach are reduced rapidly, compared with the sterile-insect technique alone.

Table 14.4: Trend of the Hypothetical Population When Insecticides Are Used, Followed by Sterile-Insect Releases

Gene-ration	*No. of Sterile Males Released*	*Without Insecticides*		*With Initial Insecticide Application – 90% Kill*	
		No. of Females	*Ratio of Sterile-To-Normal Males*	*No. of Females*	*Ratio of Sterile-To-Normal Males*
1	9,000,000	1,000,000	9:1	100,000	90:1
2	9,000,000	500,000	18:1	5,495	1,638:1
3	9,000,000	131,000	68:1	17	529,412:1
4	9,000,000	9,535	944:1	0	
5	9,000,000	50	180,000:1		
6	9,000,000	0			

A mathematical model of the sterile-insect technique discussed by E. S. Krafsur and coworkers is as follows:

$$W_{n+1} = \left[\left(W_n \ x \ \frac{W_n}{W_n + (R \ x \ C)} \right) + M \right] x \ I$$

Where:

W = number of wild individuals of a sex (the first *W* is egg-laying females and the others are males)

N = generation number

C = competitiveness (if released males are equally competitive to wild females, this value equals 1.00)

M = number of immigrant females inseminated with fertile sperm and unwilling to mate

I = effective rate of population increase

In this equation, if *R* is constant over successive generations, there would be an accelerated decline of population numbers toward eradication as the *R:W* ratio progressively improved. Eradication would be prevented if:

1) *M* is not zero
2) *I* increases because of density-dependent factors OR
3) *C* declines because released males consistently fail to find localized wild populations

3.3 Circumstances for Application

Several pest situations are envisaged for use of the sterile-insect technique:

1) Against well established pests when they reach low points in their density cycles (either within a season or between seasons;
2) Against newly introduced pests or established pests spreading into new areas;
3) With other tactics like insecticides and cultural procedures which precede sterile-insect releases and
4) Against isolated populations like those on islands and other such situations.

In all situations, an areawide programme must be imposed for complete success.

3.4 Sterilizing Insects In A Natural Population

The idea of sterilizing insects in a natural population was advanced several years ago when it was found that certain chemicals called **chemosterilants,** had potential in this regard. The subsequent discovery that these chemicals presented unacceptable human health and environmental hazards discouraged further advancement of the approach. Even though not practical presently, future developments could change the acceptability of the method; therefore, a brief explanation of this idea is appropriate. Chemosterilants used are TEPA, HEMPA, BUSULFAN, etc.

Sterilizing insects in a natural population should not be confused with the sterile-insect release procedure. Although sterility is involved in both instances, the mechanisms of suppression of each is quite different. Whereas mating is required for suppression in sterile-insect release programmes, population reproductive rates are reduced directly by the sterilization of individuals in the natural population. Here, both males and females of the population are sterilized, which in regard to reproductive capacity is the same as killing them; they will not add individuals to the next generation. Moreover, the sterilized individuals, still being active, can mate with individuals of the population that were not sterilized, further reducing the reproductive potential. This latter phenomenon behave similarly to the release method and, with this approach has been called the **bonus effect.**

To achieve this bonus effect, the sterility technique must not eliminate mating behaviour and competitiveness of the sterilized insects. Indeed, unless a high level of competitiveness is retained, sterilizing feral (wild) individuals generally would have the same effect on reproduction as killing them outright with an insecticide. Conversely, fully competitive sterile insects theoretically would be capable of reducing reproduction in normal individuals of the population in proportion to the sterile-insect numbers. For instance, if 90 percent sterility in the population is achieved, that percentage would be similar to mortality from an insecticide. However, unlike the insecticide, the sterilized individuals would further reduce reproduction in the 10 percent of normal females by 90 percent.

A hypothetical example of the rapid population reduction that could be achieved with an effective chemosterilant, along with a comparison with insecticides and sterile-male releases is shown in Table 5.

Table 14.5: Trend of the Hypothetical Population Comparing Application with an Insecticide, Sterile-Male Release and Application of a Chemosterilant

Gene-ration	*No. of Females with Insecticide – 90% Kill*	*No. of Females with Sterile Releases (Ratio 9:1)*	*No. of Females with Chemosterilant – 90% Sterility*
1	1,000,000	1,000,000	1,000,000

2	500,000	500,000	50,000
3	250,000	131,579	2,500
4	125,000	9,535	125
5	62,500	50	6
6	31,250	0	0

The method of sterilizing feral insects in their environment has been tested extensively on a worldwide basis. Most research on this approach has focused on the housefly, *Musca domestica* and several mosquitoes (Diptera: Culicidae) in isolated areas. In house fly studies, chemosterilants have been combined with highly selective baits to maximize exposure of the target organisms and reduce risk to other species. With pilot studies, using the chemosterilant TEPA, in a granular bait (67 percent cornmeal, 15 percent sugar, 15 percent powdered milk, 2.5 percent powdered eggs and 0.5 percent TEPA), house flies were virtually eliminated around a dump on Bahia Honda Key IN Florida during a 5-week period. Another even more ambitious programme with the house fly on Grand Turk Island in the West Indies caused large reductions in the fly population; however, the programme was considered only moderately successful because final eradication was not achieved.

The advantage of sterilizing individuals in the natural population are very clear. With the bonus effect, mush higher levels of effectiveness can be achieved than with direct mortality agents like insecticides. In addition, many of the obstacles of the sterile-insect release technique are eliminated, particularly the expensive and sometimes formidable task of rearing large numbers of insects for release. Yet the problem remains finding safe, efficient sterilizing agents that can be applied in the environment. Until this problem is solved, we would not expect much use of this tactic.

3.5 Methods of Sterilization

The concept of autocidal control is sound in principle, but its application relies greatly on acceptable procedures to sterilize insects. Without these, as seen in the concept of sterilizing natural populations, progress toward application can be agonizingly slow or halted completely. During the development of the approach, both ionizing radiation and chemicals have been found to cause insect sterility but the former has been used more successfully.

3.5.1 Ionizing Radiation

The sterilizing effects of X-rays on insects were observed as early as 1916 with adult cigarette beetles, *Lasioderma serricorne* and was the first form of radiation investigated. These and other investigations with X-ray caused mutations in pomace flies, Drosophila *melanogaster*, eventually led to the discovery by R. C. Bushland that pupae of the screwworm, when irradiated near adult emergence could result in competitive, sterile adults.

With the development of the atom bomb after World War II, it became much more efficient to work with manufactured isotopes, primarily those producing gamma rays. Further studies showed little difference between certain X-rays and gamma rays in treating insects and most subsequent programmes have utilized gamma radiation, with cobalt or cesium as the source.

High-energy radiation exacts its genetic effects by chromosome breakage and point mutations of DNA. After irradiation, gametes are produced, but they carry dominant lethal mutations so that the zygotes formed die early in development.

The main objective of irradiation is to sterilize insects without greatly affecting their ability to live, mate and carry on otherwise normal life functions. In practice, both sexes are irradiated, sterilized and released but sterile females have no desired effect on the outcome. Because species vary in the radiation dose required to achieve sterilization, considerable laboratory study must be conducted with various doses on different insect stages to establish the appropriate procedures.

In many instances, the pupal stage is the most appropriate for irradiation. Usually less active than larvae and adults, pupae are easy to handle and can be sterilized with relatively low radiation doses after, most adult structures are formed. Doses required for sterility in adults are often about the same as those in older pupae, but adults are usually more difficult to manipulate. Both eggs and larvae are radiosensitive, and the radiation levels required to induce sterility often cause premature death or abnormal adults. In some organisms, higher levels of radiation are required to sterilize females than males. Sterilizing doses also vary greatly among insect species. In particular, the Lepidoptera require high does, which in many instances causes a great decrease in competiveness. Overall, does required for radiosterilization of insects are much greater than those for mammals.

Table 14.6: Radiation dose required for different species and stages for sterilization (expressed as rads - radiation absorbed dose).

Insect	**Stage**	**Dose**
Housefly	2-3 day pupae	3000 rads
Screw worm	5 day pupae	2500 rads
	1 day adult	5000 rads

3.5.2 Chemosterilization

Chemosterilants are chemicals which interfere with the reproductive capacity of an insect.
The ability of some chemicals to sterilize insects as well as some of the drawbacks of this method have already been mentioned. When applied before onset of meiosis, chemosterilants prevent gamete production. Knowing this, we are not surprised to learn that such chemicals prevent all types of cell reproduction and have received much development in cancer therapy (chemotherapy). Indeed, chemotherapy research probably gave impetus to the suggestions of chemical use for insect sterilization.

Chemosterilants can be divided into four basic groups;

i. Alkylating agents

Presently, these agents represent the largest class of chemosterilants and their effects are similar to those of X-rays and gamma rays. These agents cause multiple dominant lethal mutations or severely injured genetic materials in the sperm or egg. They inhibit nucleic acid synthesis, inhibit gonad development and produce mutagenic effect (e.g.) TEPA, Chloro ethylamine.

Alkylating agents are unstable in the environment and degrade rapidly. Possible contamination of food and water with even small residues, however, makes crop applications presently unfeasible. Safe applications are possible only under laboratory conditions where these materials may be used to sterilize insects in insect-release programmes. Such an approach has been attempted with the boll weevil, *Anthonomus grandis*, by incorporating busulfan, an alkylating agent, into the diet of mass-reared beetles and releasing them into test areas. More recently, an insect growth regulator, diflubenzuron, has been used in the adult diet, followed by gamma irradiation to achieve effective male sterilization.

ii. Antimetabolites

Chemicals having structural similarity to biologically active substances. They interfere with nucleic acid synthesis. e.g. 5-Fluororacil, Amithopterin

iii. Phosphorus amides

iv. Triazines

3.6 Sterile-Release Programmes

Much effort has been directed toward developing the sterile-insect release technique for practical use. The USDA has been particularly responsible for many studies and pilot programmes that have advanced the concept and the agency has been the primary force behind large-scale implementations.

A development from these areawide programmes has been the so-called concept of **total population management (**TPM). The TPM approach attempts to use all available means to eradicate a pest over a broad area. This ibjective is not new, but until the development of the sterile-male technique, it had been considered nearly impossible.

Pest eradication has been realized in only a few instances where sterile-insect releases were made, but successful degrees of suppression have been achieved in several other instances. Some of the most important examples of the technique follow.

i. Screwworm eradication and suppression

The most dramatic success with the sterile-insect technique was achieved with eradication of the screwworm fly from the United States, Mexico, and most of Central America. As a parasite of livestock, this fly lays 250 to 300 eggs in wounds and developing larvae feed on tissues and enlarge the open wound. Such feeding attracts still other flies to oviposit, and death of the parasitized animal may occur in as few as 10 days. Before the sterile-male release programme, livestock losses were estimated at $20 million annually in the southern United States and $50 to $100 million in the southwestern states. During a particularly severe outbreak in 1935, 1.2 million cases of infestation and 180,000 livestock deaths was reported in the United States.

Use of the sterile-male technique against this insect was conceived in the early 1950s. After 2 years of research, field trails on the island of Sanibel (off the west coast of Florida) gave encouraging results. This test preempted a larger pilot programme in 1954on the larger, more isolated island of Curacao, off the coast of Venezuela. Here, 400 sterilized males per square mile per week were released over a period of about 3. Months (four to five generations). The programme resulted in eradication from the island and demonstrated the potential of the technique.

An even larger programme, financed jointly by the USDA and the livestock industry in the Southeast was implemented in 1958. Up to 50 million sterile flies of both sexes were produced each week and more than 2 billion were released over an 18-month period. The area involved 85,000 square miles, including Florida and parts of Georgia and Alabama. In this programme, more than 40 tons of ground meat were required each week to rear flies and 20 aircraft were used to release them.

This campaign resulted in complete eradication of screwworm populations from Florida. Subsequent recurrences of the pest from importation of infested animals have been eradicated quickly by treatment of the animals and additional sterile-fly releases. The cost of the Florida programme was estimated as $10 million, but it has been credited with saving southeastern livestock producers many times that amount.

With eradication achieved in Florida, attention turned to screwworm infestations in the southern parts of Texas, New Mexico, Arizona and California. In these instances, flies invaded the United States from Mexico and produced significant infestations. To eliminate the pest and prevent future invasions, the strategy of creating a **fly-free barrier zone** was advanced. Subsequently, a fly-rearing plant was established in Mission, Texas, capable of producing more than 150 million flies per week. Beginning in February 1962, sterile flies were released along the border between Texas and Mexico. In 964, the releases were extended to include the Mexican border of Arizona and California. These latter releases created a fly-free zone 2,000 miles long by 300 to 500 miles deep; the zone served as a "barrier" to northward movement into the United States. Using this strategy, fly infestation reports in the United States dropped from more than 50,000 in 1962 to about 150 by 1970.

Unfortunately, the screwworm populations did not remain low. Infestation frequency began a slow increase in 1971 and reached an alarming 95,642 reports by 1972, despite continued fly releases. Release rates were increased as much as five-fold but infestations remained at an unacceptable level. Later, it was hypothesized that new strains of laboratory flies were inadvertently produced that were less active and competitive for mates than feral flies. Following modified procedures and repeated efforts, the effectiveness of the programme was renewed by 1977.

In 1981, the Mission, Texas rearing facility was closed and replaced by a more efficient plant in Tuxtla Gutierra, Mexico, opened in 1976. The Mexican plant is capable of producing up to 500 million flies per week.

Along with increased rearing capabilities, strategies were developed to gradually push the fly-free barrier zone south to the Tehuantepec Isthmus, where a shorter barrier (only 140 miles) was necessary. This objective was established by a joint Mexico-United States agreement in 1972 and the programme was initiated in 1976. Among the new tactics used in this programme have been the application of poison baits followed by releases of new-strain flies into the reduced populations.

ii. Sterile fly for African Trypanosomiasis

Sleeping sickness or the African trypanosomiasis is a parasitic disease in humans. Caused by protozoa of genus *Trypanosoma* and transmitted by the Tsetse fly, the disease is endemic in

certain regions of sub-saharan Africa, covering about 36 countries and 60 million people. It is estimated that 50,000 - 70,000 people are infected, and about 40,000 die every year. Three major epidemics have occurred in the past hundred years, in 1896 - 1906, 1920, and 1970.
Studies of the tsetse fly show that females generally only mate once in their lifetimes and very rarely mate a second time. Once a female fly has mated, she can then produce continual offspring throughout her short life.

The **sterile fly** is an innovative solution to the problem of the African trypanosomiasis. Specially bred male Tsetse flies are sterilized through irradiation process. These sterilized male flies are then released into areas where sleeping sickness is prevalent, and then mate with the females. Because the male is sterile, and the females mate only once, the population of Tsetse flies in the affected area will drop. Studies have shown that this process has been very effective in preventing sleeping sickness in people who live in the area.
Since sleeping sickness is fatal without treatment and infected people can be without symptoms for months, the release of sterile flies into affected areas leads to greater levels of health and economic activity.

3.7 Requirements of Sterile-Insect Programmes

1. A method inducing sterility without impairing sexual behaviour of insects.

2. Mass rearing of the insects economically: Even with low numbers in the natural population, most programmes call for millions of insects to be produced and released weekly over a period of several weeks. This capability sometimes necessitates development of a synthetic diet on which healthy and environmentally competitive insects can be reared.

3. Information on population density and its rate of increase (reproductive rate)

4. The released insects must not cause damage to the crops, livestock or human beings: For instance, the inundation of insects capable of transmitting arboviruses or plant pathogens in an area probably would be unacceptable.

5. Good intermingling of released and natural population

6. Releasing sterilized insects when the wild population is abundant

7. This method is effective against newly introduced pest or isolated insect population as in island.

8. There should be high sterile to fertile (S:F) ratio for quicker control.

3.8 Limitations / Drawbacks of Sterile-Insect Programmes

1. Not effective against insects which are prolific breeders

2. Sterilizing and mutagenic effect of chemosterilants and irradiation cause problems in higher animals and man (Carcinogenic and mutagenic)

3. As with insecticide treatment, repeated treatment is sometimes required to suppress the population before the use of sterile insects.

4. Sex separation could be difficult for some species, though this can be easily performed on Medfly and screwworm, for example.

5. Radiation treatment in some cases affects the health of males, so sterilized insects in such cases are at a disadvantage when competing for females.

6. The technique is species specific. For instance, there are 22 species of Tsetse fly in Africa, and the technique must be implemented separately for each.

7. Standard operating procedures of mass rearing and irradiation do not leave room for mistakes. Since the fifties, when SIT was first used as a means for pest control, several failures have occurred in different places around the world where non-sterilized artificial produced insects were released before the problem was spotted.

8. Application to large areas should be long lasting, otherwise migration of wild insects from outside the control area could repopulate.

9. The major drawback to this technique is that the cost of producing such a large number of sterile insects is often prohibitive in poorer countries.

SIT programs will benefit tremendously if genetic methods can be developed that enable only male insects to be reared as has already been done for the medfly. In addition, more appropriate artificial diets for larvae, and hormonal, nutritional, microbiological, and semiochemical treatments for adults, could make major contributions through improved economy and insect quality.

Economic benefits of SIT has been demonstrated in various cases. For example, direct benefits of screwworm eradication to the North and Central American livestock industries are estimated to be over $1.5 billion/year, compared with a total investment over half a century of close to $1 billion. Mexico protects a fruit and vegetable export market of over $3 billion/year through an annual investment of ca. $25 million, and medfly-free status has been estimated to have opened markets for Chile's fruit exports of up to $500 million. Eradication of tsetse has resulted in major socio-economic benefits for Zanzibar. When implemented on an area-wide basis and with economies of scale in the mass rearing process, the use of SIT for suppression is cost competitive with conventional control, in addition to its environmental benefits.

4.0 CONCLUSION

In this unit, we have treated the definition of semio-chemicals, the theoretical background, the methods of sterilization, examples of sterile release programmes and the requirements and drawback of sterile release programmes.

5.0 SUMMARY

Irradiation done by exposing insects to α, β, γ radiations, X rays and neutrons. Of these, γ-radiation by ^{60}Co (cobalt) with its half-life of 60 years is the most common method. Irradiation causes following sterility effects in insects;

• Infecundity

• Aspermia

• Dominant lethal mutation

6.0 TUTOR-MARKED ASSIGNMENTS (TMA)

1. define the term sterile-insect technique
2. discuss the theoretical background to the use of SIT
3. What the circumstances of application of SIT
4. Mention the methods of sterilization
5. Give examples of sterile release programmes
6. What are the requirements of sterile relase programmes
7. State the limitations or drawbacks of sterile release programmes

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UNIT 3: PEST FORECASTING

CONTENTS

1.0 INTRODUCTION

In agriculture, considerable losses in crop produce occur due to the infestation of various pests and diseases. Such losses can be reduced to a great extent if their occurrence is known in advance so that timely remedial measures can be taken. Thus, there is also a need to develop forewarning systems which can provide advance information for outbreak of pests / diseases attack so that protection measures can be implemented before the actual onset of the damage.

2.0 OBJECTIVES

At the end of this unit, you should be able to;

- explain the terms; pest monitoring, pest surveillance, pest forecasting and economic injury level
- state the objective of pest surveillance
- calculate the economic injury level with a given set of data
- state the uses of pest forecasting and the types.

3.0 MAIN CONTENT

3.1 Pest Monitoring

Monitoring phytophagous insects and their natural enemies is a fundamental tool in IPM – for taking management decision

Monitoring - estimation of changes in insect distribution and abundance
- information about insects, life history
- influence of biotic and abiotic factors on pest population

3.2 Pest Surveillance

Refers to the constant watch on the population dynamics of pests, its incidence and damage on each crop at fixed intervals to forewarn the farmers to take up timely crop protection measures.

Three basic components of pest surveillance are;
Determination of

a. the level of incidence of the pest species
b. the loss caused by the incidence
c. the economic benefits, the control will provide

Objectives of Pest Surveillance

- to know existing and new pest species

− to assess pest population and damage at different growth stage of crop

− to study the influence of weather parameters on pest

− to study changing pest status (Minor to major)

− to assess natural enemies and their influence on pests

− effect of new cropping pattern and varieties on pest

3.3 Pest Forecasting

Forecasting of pest incidence or outbreak based on information obtained from pest surveillance.

Uses

- Predicting pest outbreak which needs control measure
- Suitable stage at which control measure gives maximum protection

Two types of pest forecasting

a. Short term forecasting - Based on 1 or 2 seasons

b. Long term forecasting - Based on affect of weather parameters on pest

Accurate forecasting of pest attacks helps control programme to be effective. It depends on the established relationship among the following factors;

1. stage of development of the crop
2. stage of the development of the pest
3. environmental factors

3.4 Survey

Conducted to study the abundance of a pest species

There are two types of survey;

i. Roving survey

- Assessment of pest population/damage from randomly selected spots representing larger area
- Large area surveyed in short period
- Provides information on pest level over large area

ii. Fixed plot survey

Assessment of pest population/damage from a fixed plot selected in a field. The data on pest population/damage recorded periodic from sowing till harvest. e.g. 1 sq.m. plots randomly selected from 5 spots in one acre of crop area in case of rice. From each plot 10 plant selected at random. Total tillers and tillers affected by stem borer in these 10 plants counted. Total leaves and number affected by leaf folder observed. Damage expressed as per cent damaged tillers or leaves. Population of BPH from all tillers in 10 plants observed and expressed as number/tiller.

Qualitative survey - Useful for detection of pest

Quantitative survey - Useful for enumeration of pest

3.5 Sampling Techniques

Absolute sampling - To count all the pests occurring in a plot

Relative sampling - To measure pest in terms of some values which can be compared over time and space e.g. Light trap catch, Pheromone trap

3.5.1 Methods of sampling

a. *In situ* counts - Visual observation on number of insects on plant canopy (either entire plot or randomly selected plot)

b. Knock down (Sudden trap) - Collecting insects from an area by removing from crop and counting

c. Netting - Use of sweep net for hoppers, odonates, grasshopper

d. Narcotized collection - Quick moving insects anaesthesised and counter

e. Trapping ;
   Light trap - Phototropic insects
   Pheromone trap - Species specific
   Sticky trap - Sucking insects
   Bait trap - Sorghum shootfly - Fishmeal trap
   Emergence trap - For soil insects

f. Crop samples - Plant parts removed and pest counted e.g. Bollworms

3.5.2 Stage of Sampling

- Usually most injurious stage counted
- Sometimes egg masses counted - Practical considerations
- Hoppers - Nymphs and adult counted

3.5.3 Sample Size

- Differs with nature of pest and crop
- Larger sample size gives accurate results

3.5.4 Decision Making

- Population or damage assessed from the crop
- Compared with ETL and EIL
- When pest level crosses ETL, control measure has to be taken to prevent pest from reducing EIL.

3.6 Economic Injury Level

- Defined as the lowest population density that will cause economic damage
- Also defined as a critical density where the loss caused by the pest equals the cost of control measure

EIL can be calculated using the following formula:

$$EIL = \frac{C}{V \times I \times D \times K} \quad \text{(OR)} \quad \frac{C}{VIDK}$$

EIL = Economic injury level in insects/production (or) insects/ha

C = Cost of management activity per unit of production (Rs./ha)

V = Market value per unit of yield or product (Rs./tonne)

I = Crop injury per insect (Per cent defoliation/insect)

D = Damage or yield loss per unit of injury (Tonne loss/% defoliation)

K = Proportionate reduction in injury from pesticide use

Worked example of EIL

Calculate EIL in terms of pest population/ha with the following figures;

C	= Management cost per unit area	= Rs.3,000/- per ha
V	= Market value in Rs./unit product	= Rs.1,000/tonne
I	= Crop injury/pest density	= 1% defoliation/100 insects
D	= Loss caused by unit injury	= 0.05 tonne loss/1% defoliation
K	= Proportionate reduction in Injury by pesticide application	= 0.8 (80% control)

$$EIL = \frac{C}{V \times I \times D \times K} = \frac{3000}{1000 \times 0.01 \times 0.05 \times 0.8}$$

EIL = 7500 insects/ha

Economic threshold level (ETL) or Action threshold

- ETL is defined as the pest density at which control measures should be applied to prevent an increasing pest population from reaching Economic Injury Level (EIL)
- ETL represents pest density lower than EIL to allow time for initiation of control measure

Factors Influencing ETL and EIL

a. Market value of crop
b. Management costs
} Primary factors

c. Degree of injury per insect
d. Crop susceptibility to injury
} Secondary factors

a. Market value of crop : when crop value increases, EIL decreases and vice-versa

b. Management of injury per insect : when management costs increase, EIL also increases

c. Degree of injury per insect

- Insects damaging leaves or reproductive parts have different EIL (Lower EIL for Rep. part damages)
- If insects are vectors of disease EIL is very low even 1 or 2 insects if found - management to be taken
- If insects found on fruits - Marketability reduced - EIL very low

d. Crop susceptibility to injury

- If crop can tolerate the injury and give good yield. EIL can be fixed at a higher value
- When crop is older, it can withstand high pest population - EIL can be high

Tertiary factors

Weather, soil factors, biotic factors and human social environment. These tertiary factors cause change in secondary factors thereby affect the ETL and EIL.

4.0 CONCLUSION

Ever notice how some pests occur consistently and cause problems every year, while others are more sporadic? Sometimes the more sporadic pests are the more difficult to control, and they may occur unexpectedly. Obviously, it would be beneficial to be able to predict

outbreaks, especially those that don't seem to occur with much regularity. Or, at least, detect the pest populations at an earlier stage so as to provide more control options.
For example, newer insecticides targeted at grubs such as imidacloprid and halofenozide generally are more effective when directed against earlier stages. Some “natural” products, such as those containing the naturally-occurring growth regulator azadirachtin, will work best when applied against early instar caterpillars. A general rule for mole cricket management is that almost all products work most effectively when applied against the smaller, early instar crickets.

Obviously, there is a need to be able to predict and characterize insect life stages so that you can target specific products against certain stages. In addition, some pest controls operators are searching for ways to use many of these newer products with lower rates. Either way, finding a method to accurately time the applications is a challenge. This is particularly true for soil insects such as white grubs and mole crickets because these insects spend much of their life in the soil and remain somewhat hidden. It's often hard to know exactly what is going on.
Scouting and monitoring pests is a good way to stay on top of pest abundance and development. Techniques used to keep track of pests range from light traps for moths to pheromone traps for pests like Japanese and Oriental beetles, to soapy water flushes for mole crickets and caterpillars, to digging in the soil for white grubs. These techniques can be time-consuming, all the more so if you don't have at least a rough idea of when to search.
Fortunately, there's a better way than continuous sampling.

Insects: facts of life

All insects are cold-blooded. That is, their growth and development depends on the temperature of their environment. The warmer it is, the faster the insect develops and the cooler the temperature, the slower the development. There is usually a lower threshold for development, and often this is roughly 50°F (10°C), although some insects may actually develop at temperatures slightly below that level. Some insects have an upper threshold as well. In some cases, once it gets warmer than the upper threshold, the insect's developmental rate may not increase any further.
Other factors may play a role in an insect's overall development, such as day length, relative humidity, soil moisture and others. However, temperature is usually the main element that

influences insect development. In cold regions, winter temperatures bring all pest development to a standstill. In areas farther to the south, some development may continue during warm spells in the winter.

Research has shown that many insect populations can be forecast or predicted by using either soil or air temperatures. However, because plant growth is also regulated by temperatures (as well as day length) it is sometimes possible to relate some stage of plant development (such as flowering) to the development of a certain stage of a specific insect. This is called *phenology*, and can be much easier than constant monitoring and logging of data.

5.0 SUMMARY

In this unit, various terms used in pest forecasting, the uses and types of pest forecasting and how to calculate EIL have been treated.

6.0 TUTOR-MARKED ASSIGNMENT (TMA)

1. Define the following terms;
   a. Pest monitoring
   b. Pest surveillance
   c. Pest forecasting
   d. Economic injury level

2. State the methods of sampling

3. Mention the objectives of pest surveillance

4. State the use and types of pest forecasting

7.0 FURTHER READING / REFERENCES

http://www.culturaapicola.com.ar/apuntes/libros/20_Principos_aplicados_entomologia.%20(1).pdf – Principles of Applied Entomology