EXTRA CREDIT COURSES

BIOPESTICIDES (18PZOECC 04)

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Objective: Students should know about the consequences of using pesticides and the appropriate remedy in this regard.

Course outcomes: At the end of the course the students will be able to

1. learn how pesticides prove injurious to fauna and flora.
2. understand various eco-friendly potions of microbes available to eradicate the economically important pests.
3. know the different botanicals and their role in pest control.
4. understand predators and parasites in pest control.
5. know the role of semio- chemicals in pestiferous insects.

UNIT: I: PESTICIDE VS BIOPESTICIDES

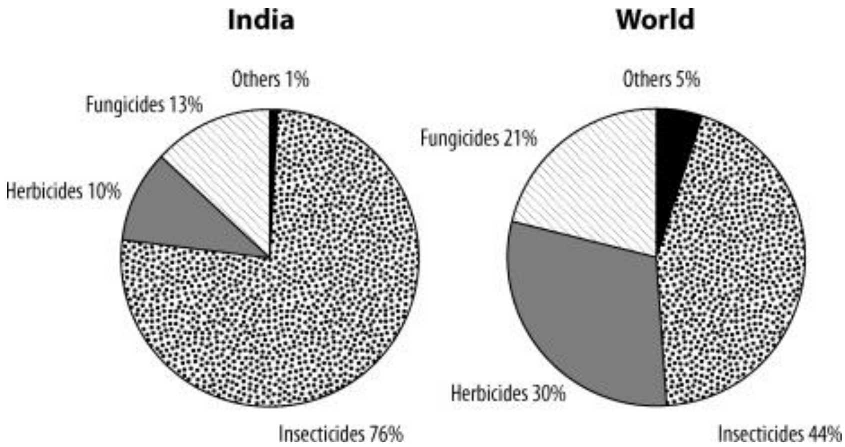
1.1.Introduction

Pesticides are chemicals that may be used to kill, among others fungus, bacteria, insects, plant diseases, snails, slugs, or weeds. These chemicals can work by ingestion or by touch and death may occur immediately or over a long period of time.

Insecticides are a type of pesticides that are used to specifically target and kill insects. Some insecticides include snail bait, ant killer, and wasp killer.

Herbicides are used to kill undesirable plants or “weeds”. Some herbicides will kill all the plants they touch, while others are designed to target one species.

Insecticides are organized into different classes such as organochlorines (Eg: DDT, BHC), cyclodienes (Eg: Aldrin, Dieldrin, Endosulfan), organophosphates (Eg: Monocrotophos, Quinalphos, Chlorpyriphos, Profenophos, Dimethoate, Phosalone, Metasystox, Acephate etc.), pyrethroids (Eg: cypermethrin, deltamethrin, Fenvalerate, λ-cyhalothrin, etc.) and formamidines (Eg: chlordimeform and amitraz). Most of these pesticides may share a common mode of action (MOA). MOA is the specific process by which an insecticide kills an insect, or inhibits its growth. **Target site of action** is the exact location of inhibition, such as interfering with the activity of an enzyme within a metabolic pathway. MOA and target site of action are often used interchangeably in practice and are combined as MOA in this learning module.



1.2. Problems

Genetics and intensive application of insecticides are two factors among several responsible for the development of insecticide resistance. Insects with genes that confer resistance to a particular insecticide or class of insecticides survive treatment and are thereby "selected" to pass on this resistance to later generations. For a complete description of the selection process, kindly see Understanding Resistance. Among all the different categories of pests, insects are known to exhibit resistance at alarming rates. Worldwide, more than 500 species of insects and related arthropods are resistant to insecticides.

Resistance may develop to only a single insecticide. However, it is more common for insects that exhibit resistance to one insecticide to be resistant (or develop resistance more rapidly) to other insecticides with the same MOA. A classic example is the house fly. Populations of this insect that became resistant to DDT in the 1950's, also exhibited resistance, with no previous exposure, to pyrethroid insecticides used decades later. DDT and pyrethroids have the same MOA. This phenomenon is known as **cross-resistance**. A closely related phenomenon, **multiple resistances**, occurs in insect populations that resist two or more insecticide classes with unlike modes of action. Insects develop this type of resistance by expressing multiple resistance mechanisms. This can happen if one insecticide is used until insects display a resistance and then another is used and the insect population becomes resistant to that one, and so on. Localized populations of Colorado potato beetle are notorious for multiple resistances to more than 50 insecticides with various modes of action. Multiple resistances is less common than cross resistance but is potentially of greater concern because it drastically reduces the number of insecticides that can be used to control the insect in question.

In contrast to resistance, insecticide **tolerance** is a natural tendency and is not a result of selection pressure. Mature caterpillars are more tolerant to many insecticides than younger ones of the same species due to differences in body size, exoskeleton thickness, and the ability to metabolize a poison. These differences are identified as tolerance or natural resistance rather than true insecticide resistance. Resistance detection methods are based on the following assays: 1. Conventional bioassays; 2. Biochemical assays; 3. Molecular assays and 4. Immunological assays.

Pesticide residue: Pesticide residue refers to the **pesticides** that may remain on or in food after they are applied to food crops. The maximum allowable levels of these **residues** in foods are often stipulated by regulatory bodies in many countries. After all, avoidance of **pesticide residues** is the #1 reason why people buy organic foods. Yet, conventional foods have more synthetic **pesticide residues** than organic ones, on average. And yet, **pesticides** are **dangerous** chemicals. Wash all your fruits and vegetables. According to the CSE, washing them with 2% of salt water will **remove** most of the contact **pesticide residues** that normally appear on the surface of the vegetables and fruits. Almost 75 to 80 percent of **pesticide residues** are removed by cold water washing. Outer leaves of cabbage, cauliflower, etc. will be removed. Various commodities are stored as follows: (a) Butter, cheese, eggs and ice cream - freeze the whole sample (b) Dry feeds - store at room temperature in airtight container (c) Feeds for fumigant analysis - seal in plastic bags and freeze (d) Fruits and vegetables freeze or refrigerate the whole sample (e) Animal fats - freeze the whole sample.

Impacts on human beings

Acute toxicity of a pesticide refers to the effects from a single exposure or repeated exposure over a short time, such as an accident during mixing or applying pesticides. Various signs and symptoms are associated with acute poisonings. A pesticide with a high acute toxicity can be deadly even if a small amount is absorbed. It can be measured as acute oral toxicity, acute dermal toxicity or acute inhalation toxicity. ***Chronic toxicity*** refers to the effects of long-term or repeated lower level exposures to a toxic substance. The effects of chronic exposure do not appear immediately after first exposure and may take years to produce signs and symptoms. Examples of chronic poisoning effects may include:

1. Carcinogenicity--ability to produce cancer or to assist carcinogenic chemicals.
2. Mutagenicity--ability to cause genetic changes.
3. Teratogenicity--ability to cause birth defects.
4. Oncogenicity--ability to induce tumor growth (not necessarily cancers).
5. Liver damage--death of liver cells, jaundice (yellowing of the skin), fibrosis and cirrhosis.
6. Reproductive disorders--such as reduced sperm count, sterility, and miscarriage.
7. Nerve damage--including accumulative effects on cholinesterase depression associated with organophosphate insecticides.
8. Allergenic sensitization--development of allergies to pesticides or chemicals used in formulation of pesticides.

The effects of chronic toxicity, as with acute toxicity, are dose-related. In other words, low-level exposure to chemicals that have potential to cause long-term effects may not cause immediate injury, but repeated exposures through careless handling or misuse can greatly increase the risk of chronic adverse effects.

Impact on environment: Pesticides can contaminate soil, water, turf, and other vegetation. In addition to killing insects or weeds, pesticides can be toxic to a host of other organisms including birds, fish, beneficial insects, and non-target plants. Insecticides are generally the most acutely toxic class of pesticides, but herbicides can also pose risks to non-target organisms.

Contamination of non-target vegetation: Pesticide sprays can directly hit non-target vegetation, or can drift or volatilize from the treated area and contaminate air, soil, and non-target plants. Some pesticide drift occurs during every application, even from ground equipment. Drift can account for a loss of 2 to 25% of the chemical being applied, which can spread over a distance of a few yards to several hundred miles. As much as 80–90% of an applied pesticide can be volatilised within a few days of application. Despite the fact that only limited research has been done on the topic, studies consistently find pesticide residues in air. In addition to killing non-target plants outright, pesticide exposure can cause sublethal effects on plants. Plants can also suffer indirect consequences of pesticide applications when harm is done to soil microorganisms and beneficial insects. Pesticides including those of new the generation, e.g., dacthal, chlorothalonil, chlorpyrifos, metolachlor, terbufos and trifluralin have been detected in Arctic environmental samples (air, fog, water, snow). Insecticides (malathion, chlorpyrifos, diazinon and endosulfan) were detected intermittently with concentrations in the range 20–780 pg/m^3.

Impacts on Non-target organisms: Pesticides are found as common contaminants in soil, air, water and on non-target organisms in our urban landscapes. Once there, they can harm plants and animals ranging from beneficial soil microorganisms and insects, non-target plants, fish, birds, and other wildlife. Chlorpyrifos, a common contaminant of urban streams, is highly toxic to fish, and has caused fish, kills in waterways near treated fields or buildings. Several cases of pesticide poisoning of dolphins have been reported worldwide. Because of their high trophic level in the food chain and relatively low activities of drug-metabolising enzymes, aquatic mammals such as dolphins accumulate increased concentrations of persistent organic pollutants and are thereby vulnerable to toxic effects from contaminant exposures. Dolphins inhabiting riverine and estuarine ecosystems are particularly vulnerable to the activities of humans because of the restricted confines of their habitat, which is in close proximity to point sources of pollution. River dolphins are among the world's most seriously endangered species. Populations of river dolphins have been dwindling and face the threat of extinction; the Yangtze river dolphin in China and the Indus river dolphin in Pakistan are already close to extinction. Earlier studies reported concentrations of heavy metals, organochlorine pesticides and polychlorinated biphenyls (PCBs), and butyltin compounds in Ganges river dolphins and their prey. The continuing use of organochlorine pesticides and PCBs in India is of concern. The Ganges river basin is densely populated and heavily polluted by fertilizers, pesticides, and industrial and domestic effluents. In addition to fish, other marine or freshwater animals are endangered by pesticide contamination. Exposure to great concentrations of persistent, bioaccumulative, and toxic contaminants such as DDT and PCBs has been shown to elicit adverse effects on reproductive and immunological functions in captive or wild aquatic mammals. Aquatic mammals inhabiting freshwater systems, such as otters and mink, have been reported to be sensitive to chemical contamination. 2,4-D or 2,4-D containing products have been shown to be harmful to shellfish and other aquatic species. The weed-killer trifluralin is moderately to highly toxic to aquatic invertebrates, and highly toxic to estuarine and marine organisms like shrimp and mussels. Since herbicides are designed to kill plants, it makes sense that herbicide contamination of water could have devastating effects on aquatic plants. In one study, oxadiazon was found to severely reduce algae growth. Algae is a staple organism in the food chain of aquatic ecosystems. Studies looking at the impacts of the herbicides atrazine and alachlor on algae and diatoms in streams showed that even at fairly low levels, the chemicals damaged cells, blocked photosynthesis, and stunted growth in varying ways. The herbicide oxadiazon is also toxic to bees, which are pollinators. Non-target birds may also be killed if they ingest poisoned grains set out as bait for pigeons and rodents. Avitrol, a commonly used pigeon bait, poses a large potential for ingestion by non target grain feeding birds. It can be lethal to small seed-eating birds. Brodifacoum, a common rodenticide, is highly toxic to birds. It also poses a secondary poisoning hazard to birds that may feed on poisoned rodents. Herbicides can also be toxic to birds. Although trifluralin was considered "practically nontoxic to birds" in studies of acute toxicity, birds exposed multiple times to the herbicide experienced diminished reproductive success in the form of cracked eggs. Exposure of eggs to 2,4-D reduced successful hatching of chicken eggs and caused feminisation or sterility in pheasant chicks. Effects of some organochlorines (OCs) on fish-eating water birds and marine mammals have been documented in North America and Europe. Despite the continuing usage, little is known about the impacts of OCs in bird populations in developing countries. Among the countries that continue to use OCs, India has been one of the major producers and consumers in recent years. As a consequence, wild birds in India are exposed to great amounts of OC pesticides. Use of OCs in tropical countries may not only result in exposure of resident birds but also of migratory birds when they visit tropical regions in winter. The Indian sub-continent is a host to a multitude of birds from western Asia, Europe and Arctic Russia in winter. Hundreds of species of waterfowl, including wading birds such as plovers, terns and sandpipers, migrate each winter to India covering long distances. While concentrations of OC pesticides in wholebody homogenates of birds have been reported elsewhere, concentrations of OCs in prey items and in eggs of Indian birds have not been reported.

A few studies related to the decline in the populations of bats in various parts of the world to OC exposure were also being conducted. The world population of bats was estimated to be 8.7 million during 1936 and it declined to approximately 200,000 in 1973. It has recovered slightly to an estimated number of 700,000 in 1991. High tissue concentrations of *p,p'*-dichloro-diphenyl-dichloroethene have been found in bats in Carlsbad Caverns in Mexico and in New Mexico in the USA. These observations indicate that bats can accumulate high concentrations of OCs and may be affected by their potential toxic effects. The flying fox or the new world fruit bat, short-nosed fruit bat and Indian pipistrelle bat are resident species and are very common in South India. Their habitat is mainly agricultural areas, rock caves, and abandoned houses in domesticated areas. Insects constitute an important diet for many bats, allowing the passage of OCs in their body. Several studies found OC pesticides and PCBs in livers and eggs of birds in developed countries. Similarly, several studies reported OCs in a variety of biota including humans and wildlife from India. However, no study has used whole body homogenates of birds, which is important to evaluate bio-magnification features and body burdens of OCs. Earlier studies used specific body tissues to estimate bio-magnification of OCs. However theoretically, estimation of bio-magnification factors requires whole body concentrations rather than specific tissue concentrations.

1.3. Biopesticides

Definitions: Biopesticides are certain types of pesticides derived from such natural materials as animals, plants, bacteria, and certain minerals. For example, canola oil and baking soda have pesticidal applications and are considered biopesticides.

Types of biopesticides includes Microbial pesticides and other entomopathogens: pesticides that contain microorganisms like bacteria, fungi, or virus, which attack specific pest species, or entomopathogenic nematodes as active ingredients. Although most of these agents attack insect species (called entomopathogens; products referred to as bioinsecticides), there are also microorganisms (i.e., fungi) that control weeds (bioherbicides). Biochemical pesticides: pesticides based on naturally occurring substances that control pests by non-toxic mechanisms, in contrast to chemical pesticides that contain synthetic molecules that directly kill the pest. Biochemical pesticides fall into different biologically functional classes, including pheromones and other semiochemicals, plant extracts and natural insect growth regulators.

Advantages and Disadvantages of Biopesticides

Advantages of Biopesticides: Advantage includes: Host specificity, Ability to multiply in the target cells; No problem of toxic residue, No evidence or absence of resistance, No problem of cross resistance, Conventional technique or methods for applications, Permanent control of pest or long persisting effect, Ideally suited for integration with most other plant protection measures used in IPM programme, No fear of environment pollution and hence ecofriendly. Biopesticides have benefits and limitations effect for the environment, human life, or agricultural products. The benefits of biopesticides as follow:

1. the ability to provide alternative modes of action to traditional products which makes them a critical component in most IPM programs;
2. are thought to turn on plant defense responses. Such products should be applied before infection to be effective;

3. have the short residual time, low toxicity, and reduced risk to non-target organisms or the environment; or mostly have host specific target;
4. are often unable to compete with native soil microorganisms, they tend to persist at levels ineffective for control;
5. registration in less time than conventional chemical products because biopesticides exhibit minimal impact on the environment and humans; low persistent, or mostly residual effect biodegradable and self perpetuating; less harmful on beneficial flora and fauna;
6. the ability to extend the life of conventional chemicals by providing resistance management benefits in agricultural programs;
7. exemption from tolerances, such as reduced pre-harvest restrictions and application in environmentally sensitive areas, which permits biopesticides that have no Maximum Residue Levels (MRLs) to be used on crops intended for export and in urban settings;
8. a high degree of worker safety and the shortest reentry intervals allowed by law;
9. value-added benefits, such as improved plant health, yields and quality and an increase in beneficial, in both traditional and organic cultivation programs.

Disadvantages or Limitation: High selectivity or host specificity, Requirement of additional control measures. Important limitations are as follows:

1. Biopesticides may appear to be effective when actually conditions became unfavorable for the disease to develop or the pathogen was not present. The earlier in disease development that applications of a product are started the more effective will the product be.
2. Disease spots (lesions) cannot be ‘cured’ and once a pathogen has infected a plant it cannot be killed, even with most conventional fungicides, in contrast with insect pests which remain on plant surfaces and are accessible to treatment.
3. Data on the efficacy of biopesticides such as the product's mode of action, residual time, and target disease(s) is limited;
4. Product performance can also be affected by spray coverage and frequency of application.
5. Sometimes in efficacy experiments the pathogen is introduced artificially rather than relying on natural inoculums. This may result in disease pressure that is greater or less than what would occur naturally.
6. Some products have continued to be developed and improved following registration, thus results obtained with an early formulation might not reflect the degree of control obtainable with the current formulation.

7. Performance of some products can be improved by using an adjuvant, but on the other hand, it has been suggested that some products have been negatively affected by the adjuvant used.
8. Laboratory testing provides an indication of product activity, but these results alone are not sufficient for predicting field efficacy because of the many environmental factors that can affect performance.
9. Most efficacy studies have not been conducted in organic systems, where healthy soils, crop rotations, and biodiverse agroecological environments may affect outcomes.

Impact to the environment

Biopesticides provide growers with valuable tools on both fronts by delivering solutions that are highly effective in managing pests and diseases, without creating negative impacts on the environment and their active and inert ingredients are generally recognized as safe (GRAS). Overall, biopesticides have very limited toxicity to birds, fish, bees and other wildlife including beneficial soil microorganisms. They help to maintain beneficial insect populations, break down quickly in the environment, and may serve to reduce conventional pesticide applications through their effective use in resistance management programs. Biopesticide containing microbial antagonist(s) but not synthetic chemical could have positive impact on the environment. Some microbial antagonists have been used to control various plant pathogens. Among the microbial antagonists, the genus *Trichoderma* and *Pseudomonas* were studied and tested intensely. Biopesticides did have no Maximum Residue Levels (MRLs) so that no residue in soil will make sustainable agriculture. The microbial antagonist needs favorable condition in the environment for growth and development similar to other soil microorganisms. Beside the microbial content, carrier media for formulating biopesticide were consisted of several organic materials, such as animal broth, organic materials, or organic waste product. The media is biodegradable material so that the media did not cause residue in soil. The media is needed for stimulating soil microbial growth by providing some important nutrients. The media could also be used as nutritional source for other soil microorganisms. It is well established that complex biological interactions can take place among biocontrol pseudomonads, plant pathogens, their hosts, and other members of the microbial community. Numerous studies have also revealed that biocontrol pseudomonads are widely distributed in agricultural soils, and that multiple crop and soil factors can affect their abundance and activities.

UNIT II: MICROBIAL INSECTICIDES

2.1. Bacteria – *Bacillus thuringiensis*

Several bacterial pathogens of different insects are being used as insecticides. These are Bacillus, Clostridium, Pseudomonas, Enterobacter, Proteus, Serratia etc. Out of these, *Bacillus thuringiensis* has been used extensively. Four different toxins are produced by the B. thuringiensis and about 16 formulations have been prepared based on the above toxins. These are used in different countries like USA, Russia, France, Germany etc. Some of the registered products like Sporcine, Condor, Cutlass, Thuricide, Foil etc., are commonly used. In India, it has been found that 0.4% thuricide is more effective than malathione, endrine and DDT to control insect pests of crucifer, lac and sugarcane. In USA, different registered formulations prepared from *B. thuringiensis* are used to control pests of different crops like Alfalfa caterpillar (Alfalfa), Bollworm (Cotton), Cabbage worm (Cabbage and Cauliflower), Orange dog (Orange), Crape leaf folder (Grapes) etc.

Bacillus thuringiensis is capable of synthesizing during sporulation a protein crystal known as δ-endotoxins and it has insecticidal activity. This crystalline inclusion may contribute about 25 percent of the dry weight of the bacterium. Bt bacterium was first isolated in 1901, by the Japanese bacteriologist *S. ishiwata* from infected silk worms, *Bombyx mori*. It was subsequently rediscovered by the German biologist Berliner (1911). Berliner isolated it from infected chrysalids of the Mediterranean flour moth, *Ephestia kuehniella*, collected from a mill in the province of Thuringe. He called this bacterium *Bacillus thuringiensis*. Agronomists soon became interested in the insecticidal properties of Bt, because small amounts of preparations of this bacterium were sufficient to kill many insect larvae rapidly. The first formulation based on Bt was developed under the name "Sporéine" in France in 1938, but the first well-documented industrial procedure for producing a Bt-based product dates from 1959, with the manufacture of "Bactospéine". It was the first French patent for a biopesticide formulation. Commercial formulations of Bt composed of spore/crystal preparations obtained by culturing the bacterium in fermentors; the preparations are purified, dried and used in a granulated or wettable powder formulation for use as a spray. δ-endotoxins are highly diverse, resulting in a generally restricted activity spectrum for each individual toxin, and are innocuous to plants, animals and almost all non-target insects (ladybirds, bees and other auxiliary biological control agents). The industrial-scale production of Bt is now well controlled. It is relatively simple and competitive in terms of cost, and this obviously contributes to its success.

Bacillus thuringiensis synthesizes a number of invertebrate toxins that are mainly active against insects and has demonstrated its potential and safety as a biocontrol agent for decades. These proteins include crystal (Cry and Cyt) and vegetative (secretable) insecticidal proteins (Vip) that are highly toxic against insects. To date, *B. thuringiensis*-based biopesticides represent a clear alternative to chemical insecticides and account for about 80% of all biopesticides marketed worldwide. Chemical insecticides contaminate water and food sources, are harmful for non-target organisms and generate insect resistance. *B. thuringiensis*-based biopesticides are biodegradable and specific for their targets. In fact, their biodegradability becomes their main disadvantage since their active ingredients, the insecticidal crystal proteins, are susceptible to natural abiotic factors such as pH, temperature and sunlight. This disadvantage has stimulated the development of different encapsulation approaches intended to protect and extend the shelf life of sprayable formulations. The encapsulation of *B. thuringiensis* toxins into recombinant bacteria is a convenient tool for enhancing their field persistence, which deserves further investigations since it will allow not only to protect the active ingredient but also to concentrate secretable insecticidal proteins (e.g. Vip3 and Cry1I) 2. However, in order to be successful, the system of choice should meet the following requirements:

(i) a GRAS (General Recognized As Safe) bacterium should be used. Several GRAS bacteria have been successfully used for the production of recombinant proteins (e.g. *Bacillus megaterium* and *Bacillus subtilis*), representing clear alternatives for the production of encapsulated insecticidal proteins;
(ii) the bacterial cell wall should remain intact as a natural microcapsule. This will allow not only to protect the toxin but also the intracellular concentration of secretable insecticidal proteins;
(iii) the protein should remain encapsulated into the cell maintaining its activity. Bioassays must be performed in order to rule out loss of activity and to determine the digestibility of the bacterial cell wall by the insect and in comparison against non-encapsulated proteins;

(iv) this system should be capable of being produced at industrial scale and be competitive in the biopesticide market; therefore, expensive inductors such as IPTG (isopropyl -d-1-thiogalactopyranoside) must be avoided;

(v) the recombinant strains should not be capable of transferring recombinant DNA to wild type strains. Some systems prevent ‘leaks’ of recombinant DNA by using chemical methods that kill recombinant bacteria after protein expression (e.g. fixation of recombinant cells with lugol)1. B. thuringiensis has been the most used bacterium for the control of insect pests and human-disease vectors during the last forty years by means of the production of formulated pesticides and transgenic crops. However, the active ingredients of formulated B. thuringiensis pesticides are susceptible to different environmental factors that diminish their activity, also limiting their shelf life after application. The improvement of their residual activity will not only allow to formulate secretable toxins but also stimulate their development and increase their presence in the global pesticide market, which is currently as low as 2%

Common caterpillar pests that are controlled effectively with *Bacillus thuringiensis* var. kurstaki (Bt) include: European corn borer in corn, Indian meal moth in stored grain, cabbage looper, imported cabbageworm, diamondback moth, tomato/tobacco hornworm, gypsy moth, spruce budworm, tent caterpillars, fall webworm, mimosa webworm, bagworms, spring and fall cankerworm. Common caterpillar pests that are NOT controlled by normal applications of Bt include: corn earworm (on corn), codling moth, peach tree borer, squash vine borer

2.2. Fungal Pesticides

Fungi – Metarhizium and Beauveria;

Microbial control is an aspect of biological insect control and consists of the rational use of pathogens to maintain pest balances in agricultural environments, with increases in the numbers of other natural enemies often being observed in fields where microbial control has been used. Successful programs of microbial control using entomopathogenic fungi (EPF) to combat arthropod pests in soils and aquatic environments have been developed, principally utilizing the genera Metarhizium, Beauveria, Sporothrix, Lecanicillium, Nomuraea, Hirsutella, Aschersonia, Isaria, Paecilomyces, and Enthomophthora. Species within the genus Metarhizium are pathogenic fungi having broad ranges of insect hosts. *M. anisopliae* was found to be a species complex composed of nine species based on multilocus phylogeny. The objective of this study was to analyze some morphological, molecular and ecological aspects of *M. anisopliae.*

Metarhizium anisopliae

Metarhizium anisopliae, an anamorphic fungus which belongs to the phylum Ascomycota, is the most intensively studied species of the genus Metarhizium, considering that the teleomorph Cordyceps brittlebankisoides [= Metacordyceps brittlebankisoides was isolated from insect larva (Coleoptera: Scarabaeidae) and identifi ed as *M. anisopliae* var. majus [= *M. majus* (Johnston) Bischoff, Rehner & Humber]. The reproductive structures of *M. anisopliae* (the anamorph, the most commonly encountered form) comprise conidiophores and conidia.

Structures or blastospores and appressoria are produced by *M. anisopliae* through mycelial differentiation. Blastospores can function in certain cases as reproductive units and are produced in submerged cultures and in the hemolymph of insect hosts. The appressoria, formed at the extremity of the hyphae, may be involved in fungus pathogenicity and have the function of initiating epicuticular and procuticle penetration of the insect tegument. The production of microsclerotia by isolates of *M. anisopliae* has been observed after cultivation in liquid media with different concentrations of carbon and carbon-nitrogen. The fungal-host relationship occurs through the adhesion and germination of conidia on the surface of the insect, followed by hyphae penetration through the cuticle. The process of host colonization initiates after penetration, with the penetrating hyphae becoming thicker and ramify within the tegument and the hemocoel of the insect, forming blastospores. The hyphae continue to grow and invade various internal organs after the death of the host and will subsequently emerge from the insect body and produce conidia that disseminate and infect other individuals.

Molecular studies of the processes of host infection have shown them to be complex and multifactorial. The adhesion and penetration steps have been most closely examined and appear to be decisive to infection. The participation of an adhesin coded by the gene Mad1 in the adhesion of conidia to the cuticle of Manduca sexta Linnaeus larva was demonstrated using mutants in which this gene was deleted, with these mutants demonstrating signifi cant decreases in conidial germination, suppression of the formation of blastospores, and reduced virulence. It was described that the inhibition of phosphatase activity in the conidia of M.

anisopliae reduced adhesion to the integument of *Dysdercus peruvianus* (Pyrrhocoridae) and (indirectly) its infection. The participation of perilipin (proteins that surround lipid droplets in the cell interior) in appressoria differentiation in *M. anisopliae* has also been reported. The deactivation of the Mpl1 gene in some strains generates deficiencies in the infection process due to the formation of aspersoria with lower concentrations of lipid droplets and resultantly lower levels of osmotic pressure - resulting in difficulties in terms of hyphal penetration. Defective appressoria were also observed after the deletion of the mapka1 gene (catalytic subunit 1 of the protein kinase A). Subtilisin-type proteases have been intensively studied in penetration processes, and 10 genes are known to code for different isoforms of these enzymes (Pr1A - Pr1J) and appear to refl ect specifi city in relation to different hosts. MOS1 is another protein with an apparent role in the adaptation of fungi to the high osmotic pressure encountered in insect hemolymph. Other genes, such as Mcl1 (collagen like protein), Cag8 (which regulates the G protein signalling pathway), chi2 (endochitinase), chi3 (endoand exochitinase), and Mpk1 (phosphoketolase) are known to be involved in the host infection processes of *M. anisopliae*, with reductions in virulence if they are inactivated. SU et al. (2013) undertook comparative proteomic analyses of the conidia and mycelia of M. anisopliae (Ma1291). The proteins identified as exclusive to the conidia were involved in protective processes, appressorium formation, and the degradation of the host cuticle and exclusive proteins to mycelia were involved in biosynthetic and energy-generating metabolic processes, such as UTPglucose-1-phosphate uridylyltransferase and heatshock protein 70.

Characteristics: The optimal temperature was 25^{O}C uses a combination of enzymes and mechanical force to penetrate the host cuticle has robust conidia that are easy to formulate and store *M. anisopliae.*

Habitat: Metarhizium species are commonly thought of as soil saprophytes and are most frequently found in disturbed habitats like agricultural fields as compared to forest ecosystems. Tthese fungi form associations with plant roots in the rhizosphere M. anisopliae.

Life Cycle: The life cycle of species within this genus will be restricted to their activity as arthropod pathogens. The development has 3 stages: *M. anisopliae*

Mode of action: The spores of this fungus when come in contact with the cuticle (skin) of susceptible insects, they germinate and grow directly through the cuticle • proliferates throughout the insect's body and draining the insect of nutrients, eventually killing it.

C**rop: C**ereals, Pulses, Vegetables, Fruit crops, Cole crops, Orchards, Fibre crops, Cut flowers Ornamentals in greenhouses, nurseries, lawns and landscape.

Target pests: Root weevils, plant hoppers Japanese beetle, Black vine weevil, Spittlebug and white grubs.

Application methods: Foliar Spray (For hoppers & Bugs): The product should be sprayed on the growing plants using hand, ground or aerial spray equipment. Soil application (Root grubs & vine weevils): Metarhizium anisopliae can be sprinkled around the root – zone and incorporated into the soil either mechanically or through watering of plants. It can also be incorporated into the soil through drip irrigation systems after filtering with appropriate filters.

Tolerance : They found that all of these isolates shared similar conidial morphology but some showed the ability to germinate at colder temperatures (i.e. 5 C M. anisopliae Commercial Availability : Some registered products are also produced and used by different countries like Australia, Brazil, China, France, Japan, USA, UK etc. It was determined that there were 47 different commercially- available Metarhizium-based products available around the world different products were listed as either *Metarhizium anisopliae* or Metarhizium anisopliae var. acridum, which Green Muscle is based on. M. anisopliae

Uses : Used as a biological insecticide to control a number of pests as Grasshoppers, Termites, Thrips, caterpillars, aphids etc. Use in the control of malaria-transmitting mosquitoes.

List of some of the products, producing fungi in parenthesis and insects on which it acts are:

i. Aseronija (*Aschersonia aleyrodis*) — Whitefly of many crops.

ii. Boverin and Boverol (*Beauveria brassiana*) — Pine caterpillar, Green leaf hipper, Colorado potato beetle etc.

iii. Mycotal and Vertalec (*Verticillium lecanii*) — Whitefly and Aphids of glasshouse crop.

Plant-Incorporated Protectants (PIPs): these include pesticidal substances that are produced in genetically modified plants/organisms (GMO) (i.e., through the genetic material that has been incorporated into the plant).

2.3. Viruses – Baculoviruse, NPV

Viruses are also very much effectively used as bioinsecticide. There are three major groups of viruses that can infect different insects. These are: **(**a) Nuclear polyhedrosis viruses (NPV), (b) Granulosis viruses (GV) of Baculoviridae, and (c) Cytoplasmic polyhedrosis viruses (CPV) of Reoviridae.

The NPVs are effective against moths and butterflies, while CPVs are effective mainly on caterpillars. These are used in different countries like USA, UK, Canada, lapan, Germany etc. List if some viruses, registered trade names in parenthesis and target insects are given below:

i. NPV (ELCAR) — Tobacco budworm and Cotton bollworm.
ii. NPV (GYPCHEK) — Gypsy moth.
iii. NPV (VfROX) — European sawfly.
iv. CPV (MATSUKEMIN) — Pine caterpillar.
v. GV (MATEX) — Insects of different food crops like Codling moths.

Advantages of Microbial Pesticides

Microbial pesticides are non-toxic and non-pathogenic to non-target organisms and the safety offered is their greatest strength. Action of microbials is specific to a single group or species of pests, therefore, do not affect directly beneficial animals such as predators and parasitoids. Microbial pesticides can be used in many habitats where chemical pesticides have been prohibited. Such habitats include recreational and urban areas, lake and stream borders of watersheds, and near homes and schools in agricultural settings. Residues of microbial pesticides are non-hazardous and are safe all the time, even close to harvesting periods of the crops. They have a potential to control vectors. Some pathogenic microbes can establish in a pest population or its habitat and provide control during subsequent seasons or pest generations.

Disadvantages

Owing to the specificity of the action, microbes may control only a portion of the pests present in a field and may not control other type of pests present in treated areas, which can cause continuous damage. As heat, UV light and desiccation reduces the efficacy of microbial pesticides, the delivery systems become an important factor. Special formulations and storage procedures are necessary. Shelf life is a constraint, given their short shelf lives. Given their pest specificity, markets are limited. The development, registration and production costs cannot be spread over a wide range of pest control sales; for example, insect viruses are not widely available. Some insects develop resistance to several insect pathogens. Resistance management will have to be practiced, as it is with chemical pesticides.

UNIT. III: BOTANICAL INSECTICIDES

Naturally occurring chemicals (insect toxins) extracted or derived from plants or minerals. They are also called Natural insecticides. Fast breakdown, fast action, selectivity, toxicity, phytotoxicity, cost and availability are the important properties of botanicals. Based on the physiological activities, they are classified in to 6 groups namely

1. Repellents: Eg: DEET against Mosquitoes, flies, fleas NSKE: Lepidopteran caterpillars, BPH Basil (*Ocimum basilicum*), (*Mentha piperata*), and lemon eucalyptus (*Corymbia citriodora*)
2. Feeding deterrents/antifeedants: Eg: Azadirachtin- Desert Locust, lepidopteran caterpillars Pyrethrum-Glossina sp.
3. Toxicants: Nicotine, Anise, cumin, eucalyptus, oregano and rosemary were also reported as fumigants and caused 100% mortality of the eggs of Tribolium confusum and Ephestia kuehniella.
4. Natural grain protectants: Annonaceae, Asteraceae, Canellaceae, Labiatae, Meliaceae, Rutaceae. 1 to 2 % Kernel powder or oil.
5. Chemosterilants/ Reproduction Inhibitors: Pyrethrum: Cigarette beetle, house fly Rotenone: House fly Nicotine: House fly
6. Insect growth and development inhibitors: Eg: neem-Lepidopteran and Coleopteran larvae.

3.1. Advantages and disadvantages

3.1.1.**Advantages**: They have the following distinct advantages: I. As the active ingredients contained in them are natural substances, not synthetic chemical substances, with smooth degradation pathways in nature after application, there is less pollution to the environment; II. As the botanical insecticides have many insecticidal ingredients with special modes of action, it is difficult for the pests to develop pesticide resistance; III. They generally have features of strong selectivity, low toxicity to human, livestock and natural enemies and relatively low development and use costs.

3.1.2. **Disadvantages**: Even though the botanicals have many advantages, their practical application is limited due to many reasons. Some of the main reasons are the efficacy v/s synthetic pesticides is very low, greater application rates (i.e., > 1%), active ingredients of most essential oils evaporate rapidly except PMD (para-menthane 3, 8 diol) so frequent application is needed, poor availability of raw material, lack of protection of technology and regulation and lack of uniform quality and varied chemical composition Along with many advantages and dis-advantages there is more scope for botanicals in future studies. Some of the main future strategies are pH and salinity of solution should be taken out as it potentiate the final activity of formulation. These are eco friendly carriers so can be evaluated to deliver the active ingredient & enhance life Carrier efficacy should be enriched by hydrophilic.

3.2. Common plants with insecticidal value (neem, annona, pungamia, pyrethrins)

Neem (*Azadirachta indica* Meliaceae) Neem is ative to the Indian sub-continent, it possess fungicidal, nematicidal, bactericidal, and pesticidal properties.There is a report that Swarming desert locusts in Sudan defoliated almost all local flora except neem trees due to insecticidal properties of neem. Azadirachtin the most potent locust antifeedant discovered to date. It is used to controls leaf miners, whiteflies, thrips, loopers, caterpillars, and mealybugs as well as some of the plant diseases, including certain mildews and rusts. It acts as an insect growth regulator by disruption of moulting, growth inhibition, and malformation that may contribute to mortality. There are also effects on allatropin and juvenile hormone. Antifeedant effect is highly variable among pest species, and even those species initially deterred are often capable of rapid desensitization to azadirachtin but it is light sensitive so it will lose ½ life per day.

Substances with pesticidal properties are found in all parts of the neem tree. However, the greatest concentrations of these substances are found in the seed. Azadirachtin, the active ingredient in many pesticides currently available, is extracted from the seed kernels. Azadirachtin consists of more than 25 different but closely related compounds. In another extraction process, neem oil is extracted from the seed kernel.

Azadirachtin can act as a feeding deterrent against a number of insect pests including beetles. It reduces the level of the insect hormone Ecdysome by disrupting the insect's molting process so that the immature larvae cannot develop into adults. After treatment with neem-based pesticides, you may see insects with crippled, distorted wings. Or the immature larvae and nymphs remain in an immature stage and then die. Some soft-skinned insect larvae may be killed by direct contact with the spray. Adults are not killed by the growth regulating properties of azadirachtin but mating and sexual communication may be disrupted which results in reduced fecundity.

Neem oil works in a number of different ways. The oil forms a coating on the insect's body, blocking the breathing openings and suffocating the insect. It also has a repellent effect on certain insects and mites. Neem oil prevents the germination and penetration of some fungal spores. In one study, researchers discovered that a one percent neem oil treatment was effective in managing powdery mildew on hydrangeas, lilacs and phlox.

More than 60 insect pests may be affected by azadirachtin **including** aphids**,** beetles**,** caterpillars**,** lace bugs**,** leafhoppers**,** leafminers**,** mealybugs**,** psyllids**,** thrips **and** whiteflies**.** Due to its insect growth regulating properties, it is most effective against the immature stages of insects. For example, the immature larvae of many species in the lepidoptera family (moths and butterflies) are particularly sensitive to azadirachtin. Neem products may be registered for use on certain fruits, herbs and vegetables in addition to ornamentals. For edible crops, some neem-based products may be used up to the day of harvest.

Benefits of Neem : Neem does not persist in the environment and is degraded by ultraviolet light and rainfall. Many neem-products tend to have low mammalian toxicity. Because many neem products degrade quickly, they may have less of an effect on non-target beneficial organisms compared to some of the more traditional pesticides. Researchers found few effects on many insect predators including spiders, earwigs, and ants but flower fly larvae are very sensitive to neem sprays. Neem-based materials are compatible with integrated pest management (IPM). Regular scouting helps to insure the early detection of immature stages of many insects. Azadirachtin is compatible with insecticidal soap, superior horticultural oil and *Bacillus thuringiensis* (*Bt*). As mentioned previously, azadirachtin has a number of different modes of action. It is less likely that insects or pathogens will develop resistance to neem products compared to materials with a single mode of action.

Limitations of Neem: Botanical pesticides, such as neem, have limited persistence in the environment. Temperature, ultraviolet light, rainfall and other environmental factors can degrade neem. Repeated applications may be needed to achieve the desired result. Because it is an insect growth regulator, it is only effective against the immature stages of insects. Rescue treatments will not be effective. You will not see an immediate knockdown effect and insects may continue to feed. However, due to its repellant effects, insect feeding will be reduced. Phytotoxicity (damage to plants) may be of concern for certain formulations of neem-based products with flowers being particularly sensitive. Newly transplanted plants with limited root development or plants that are wilted or under stress should not be treated.

Annona : Annonaceae is the largest plant family in the order Magnoliales and comprises around 2,500 species and 130 genera. Except for two related North Americangenera (Asimina and Deeringothamnus), the family is entirely tropical. Annonaceae enjoyed considerable attention from plant systematists in the twentieth century. The Swedish botanist Robert Fries spent a lifelong career studying herbarium specimens, mainly originating from the Neotropics. He contributed greatly to the flora of Central America, South America, and the West Indies, especially to the knowledge of the family of Annonaceae.

Annona squamosa L. (sugar apple or sweetsop), *Annona muricata* L. (soursop, graviola, guanabana), *Annona bullata* Rich., *Annona longifolia* Kral. (long-leafed dwarf pawpaw), *Annona reticulata* L. (custard apple), *Annona glabra* L. (pond apple), *Annona jahnii* Saff., *Annona cherimola* Mill. (cherimoya) showed insecticidal activity. Each of these species contains complex mixtures of acetogenins comprising atleast 30 compounds. Sesquiterpenes and monoterpenes are the main types of compounds present in essential oils of Annona species. From the wide variety of acetogenins, squamocin and annonacin have shown the greatest impact on insects. The annonaceous acetogenins are an important group of long-chain fatty acid derivatives found exclusively in the plant family Annonaceae. Nearly 400 compounds from this class have been published in the literature since the discovery of uvaricin. The potential application of acetogenin molecules is linked. Acetogenins are mitochondrial poisons, inhibiting cellular energy production through a mode of action identical to that of the well-known botanical insecticide and fish poison, rotenone. More specifically, acetogenins block the respiratory chain at NADHubiquinone reductase (complex I) and cause a decrease in ATP levels, directly affecting electron transport in the mitochondria, causing apoptosis. Acetogenins also inhibit insect development and behaviour. Crude extracts from seeds, leaves, bark, twigs, and fruits from Annonaceae have been extensively tested in recent years for bioactivity to pest insects and related arthropods.

Pongamia pinnata (Linn) Pierre is medium sized glabraous tree popularly known as Karanja in Hindi, Indian beech in English and Pongam in Tamil. Most of the Tamil Nadu physicians of Indian system of traditional medicine Ayurveda and siddha use Pongamia pinnata to treat various kinds of diseases including diabetes mellitus. The ‘Pongam Tree’ is being cultivated in a large number of garden and along the countless roads in India and is becoming the one of the most a dmired city trees. The tree is known for its multipurpose benefits and as a potential source of biodiesel. The seeds are reported to contain on average about 28 34% oil with high percentage of polyunsaturated fatty acids. Historically pongamia has been used folk medicinal plant, particularly in Ayurveda and siddha system of Indian medicine. All part of plant have been used as a crude drug for the treatment of tumours, piles, skin diseases, itches, painful rheumatic joints wounds, ulcers, diarrhoea etc. It is well known for its application as animal fodder, green manure, timber and fish poison. It has been plenty of application in agriculture and environmental management, with insecticidal and nematicidal activity, more recently, the effectiveness of *P. pinnata* as a source of biomedicine has been reported specifically as antimicrobial and therapeutic agents

Pyrethrum : Pyrethrum is the widely and heavily used Terpenoid. It is an Axonic poison (paralysis). Pyrethrum is extracted from Chrysanthemum in Kenya and Equadar but generally extracted from *Tanacetum cinerariaefolium* (Asteraceae) flowers. ½ of the production of pyrethrum is from Australia. In pyrethrin based insecticide without synergists, there is a chance that insects may recover. Synergists increase insect mortality and the shelf life of the product. The Pyrethroids are semi synthetic, long lasting and effective.

3.3. Commercial botanicals and their utility in pest management

3.3.1. Pyrethrum and Pyrethrins

1. cinerin I- $C_{20}H_{28}O_3$
2. cinerin II- $C_{21}H_{28}O_5$
3. cinerin III- $C_{21}H_{30}O_3$
4. jamolin I- $C_{21}H_{30}O_3$
5. jamolin II- $C_{22}H_{30}O_5$
6. pyerethrin I- $C_{21}H_{28}O_3$
7. pyrethrin II - $C_{22}H_{28}O_5$

Source: Pyrethrum is the powdered, dried flower head of the pyrethrum is daisy, *Chrysanthemum cinerariaefolium*. Most of the world's pyrethrum crop is grown in Kenya. The term "pyrethrum" is the name for the crude flower dust itself, and the term "pyrethrins" refers to the six related insecticidal compounds that occur naturally in the crude material, the pyrethrum flowers. They are extracted from crude pyrethrum dust as a resin that is used in the manufacture of various insecticidal products.

Target pests: Caterpillars, aphids, leafhoppers, spider mites, bugs, cabbage worms, beetles

Mode of action: Pyrethrins exert their toxic effects by disrupting the sodium and potassium ion exchange process in insect nerve fibers and interrupting the normal transmission of nerve impulses. Pyrethrins insecticides are extremely fast acting and cause an immediate "knockdown" paralysis in insects. Despite their rapid toxic action, however, many insects are able to metabolize (break down) pyrethrins quickly. After a brief period of paralysis, these insects may recover rather than die. To prevent insects from metabolizing pyrethrins and recovering from poisoning, most products containing pyrethrins also contain the synergist, piperonyl butoxide (PBO). Without PBO the effectiveness of pyrethrins is greatly reduced.

3.3.2. Rotenone [$C_{23}H_{228}O_6$]

Source: Rotenone is insecticidal compound that occurs in the roots of *Lonchocarpus* species in South America, Derris species in Asia, and several other related tropical legumes. Commercial rotenone was at one time produced from Malaysian Derris. Currently the main commercial source of rotenone is Peruvian *Lonchocarpus*, which often is referred to as cube root. Rotenone is extracted from cube roots in acetone or ether. Extraction produces a 2-40% rotenone resin which contains several related but less insecticidal compounds known as rotenoids. The resin is used to make liquid concentrates or to impregnate inert dusts or other carriers. Most rotenone products are made from the complex resin rather than from purified rotenone itself. Alternatively, cube roots may be dried, powdered and mixed directly with an inert carrier to form an insecticidal dust

Target pests: Bugs, aphids, potato beetles, spider mites, carpenter ants

Mode of action: Rotenone is a powerful inhibitor of cellular respiration, the process that converts nutrient compounds into energy at the cellular level. In insects rotenone exerts its toxic effects primarily on nerve and muscle cells, causing rapid cessation of feeding. Death occurs several hours to a few days after exposure. Rotenone is extremely toxic to fish, and is often used as a fish poison (piscicide) in water management programs. It is effectively synergized by PBO or MGK 264.

3.3.3. Sabadilla (veratrine alkaloids) [Cevadine: $C_{32}H_{49}NO_9$ and Veratridine: $C_{36}H_{51}NO_{11}$]

Source: Sabadilla is derived from the ripe seeds os *Schoenocaulon officinale*, a tropical lily plant which grows in Central and South America. Sabadilla is also sometimes known as cevadilla or caustic barley. When sabadilla seeds are aged, heated, or treated with alkali, several insecticidal alkaloids are formed or activated. Alkaloids are physiologically active compounds that occur naturally in many plants. In chemical terms they are a heterogeneous class of cyclic compounds that contain nitrogen in their ring structures. Caffeine, nicotine, cocaine, quinine, and strychnine are some of the more familiar alkaloids. The alkaloids in sabadilla are known collectively as veratrine or as the veratrine alkaloids. They constitute 3-6% of aged, ripe sabadilla seeds. Of these alkaloids, cevadine and veratridine are the most active insecticidally. European white hellebore (*Veratrum album*) also contains veratridine in its roots. Hellebore was once commonly used in Europe and the U.S. for insect control, but is now unavailable commercially and is not registered by the US EPA.

Target pests: Grasshoppers, codling moths, armyworms, aphids, cabbage loopers, squash bugs

Mode of action: In insects, sabadilla's toxic alkaloids affect nerve cell membrane action, causing loss of nerve cell membrane action, causing loss of nerve function, paralysis and death. Sabadilla kills insects of some species immediately, while others may survive in a state of paralysis for several days before dying. Sabadilla is effectively synergized by PBO or MGK 264.

Mammalian toxicity: Sabadilla, in the form or dusts made from ground seeds, is the least toxic of the registered botanicals. Purified veratrine alkaloids are quite toxic, however, and are considered on a par with the most toxic synthetic insecticides. Sabadilla can be severely irritating to skin and mucous membranes, and has a powerful sneeze-inducing effect when inhaled. Ingestion of small amounts may cause headaches, severe nausea, vomiting, diarrhea, cramps and reduced circulation. Ingestion of very high doses may cause convulsions, cardiac paralysis, and respiratory failure. Sabadilla alkaloids can be absorbed through the skin or mucous membranes. Systemic poisoning by sabadilla preparations used as insecticides has been very rare or nonexistant.

3.3.4. Ryania

Source: Ryania comes from the woody stems of *Ryania speciosa*, a South American shrub. Powdered Ryania stem wood is combined with carriers to produce a dust or is extracted to produce a liquid concentrate. The most active compound in ryania is the alkaloid ryanodine, which constitutes approximately 0.2% of the dry weight of stem wood.

Target pests: Codling moths, potato aphids, onion thrips, corn earworms

Mode of action: Ryania is a slow-acting stomach poison. Although it does not produce rapid knockdown paralysis, it does cause insects to stop feeding soon after ingesting it. Little has been published concerning its exact mode of action in insect systems. Ryania is effectively synergized by PBO and is reported to be most effective in hot weather.

Mammalian toxicity: Ryania is moderately toxic to mammals by ingestion and only slightly toxic by dermal exposure. Ingestion of large doses causes weakness, deep and slow respiration, vomiting, diarrhea, and tremors, sometimes followed by convulsions, coma, and death. Purified ryanodine is approximately 700 times more toxic than the crude ground or powdered wood and causes poisoning symptoms similar to those of synthetic organophosphate insecticides. (Depending on exposure, organophosphate poisoning symptoms may include sweating, headache, twitching, muscle cramps, mental confusion, tightness in chest, blurred vision, vomiting, evacuation of bowels and bladder, convulsions, respiratory collapse, coma, and death.)

3.3.5. Nicotine Structure. $C_{10}H_{16}N_2O_4S$

Source. Nicotine is a simple alkaloid derived from tobacco, *Nictiana tabacum*, and other Nicotiana species. Nicotine contitutes 2-8% of dried tobacco leaves. Insecticidal formulations generally contain nicotine in the form of 40% nicotine sulfate and are currently imported in small quantities from India.

Target pests: Aphids, thrips, caterpillars

Mode of action. In both insects and mammals, nicotine is an extremely fast-acting nerve toxin. It competes with acetylcholine, the major neurotransmitter, by bonding to acetylcholine receptors at nerve synapses and causing uncontrolled nerve firing. This disruption of normal nerve impulse activity results in rapid failure of those body systems that depend on nervous input for proper functioning. In insects, the action of nicotine is fairly selective, and only certain types of insects are affected.

Mammalian toxicity. Despite the fact that smokers regularly inhale small quantities of nicotine in tobacco smoke, nicotine in pure form is extremely toxic to mammals and is considered a Class I (most dangerous) poison. Nicotine is particularly hazardous because it penetrates skin, eyes, and mucous membranes readily both inhalation and dermal contact may result in death. Ingestion is slightly less hazardous due to the effective detoxifying action of the liver. Symptoms of nicotine poisoning are extreme nausea, vomiting, excess salivation, evacuation of bowels and bladder, mental confusion, tremors, convulsions, and finally death by respiratory failure and circulatory collapse. Poisoning occurs very rapidly and is often fatal. Treatment for nicotine poisoning is symptomatic, and only immediate treatment, including prolonged artificial respiration, may save a victim of nicotine poisoning. Nicotine has been responsible for numerous serious poisonings and accidental deaths because of its rapid penetration of skin and mucous membranes and because of the concentrated form in which it is used.

3.3.6. Neem

Source. Neem products are derived from the neem tree, *Azadirachta indica*, that grows in arid tropical and subtropical regions on several continents. The principle active compound in neem is azadirachtin, a bitter, complex chemical that is both a feeding deterrent and a growth regulator. Meliantriol, salannin, and many other minor components of neem ar also active in various ways. Neem products include teas and dusts made from leaves and bark, extracts from whole fruits, seeds, or seed kernels, and an oil expressed from the seed kernel.

The product known as “neem oil” is more like a vegetable or horticultural oil and acts to suffocate insects. Neem and neem oil are often confused.

Target pests : Armyworms, cutworms, stem borers, bollworms, leaf miners, caterpillars, aphids, whiteflies, leafhoppers, psyllids, scales, mites and thrips

Mode of action. Neem is a complex mixture of biologically active materials, and it is difficult to pinpoint the exact modes of action of various extracts or preparations. In insects, neem is most active as a feeding deterrent, but in various forms it also serves as a repellent, growth regulator, oviposition (egg deposition) suppressant, sterilant, or toxin. As a repellent, neem prevents insects from initiating feeding. As a feeding deterrent, it causes insects to stop feeding. As a feeding, either immediately after the first "taste" (due to the presence of deterrent taste factors), or at some point soon after ingesting the food (due to secondary hormonal or physiological effects of the deterrent substance). As a growth regulator, neem is thought to disrupt normal development interfering with chitin synthesis. Susceptibility to the various effects of neem differs by species.

3.3.7. Citrus Oil Extracts: Limonene and Linalool

Source. Crude citrus oils and the refined compounds d-limonene (hereafter referred to simply as limonene) and linalool are extracted from orange and other citrus fruit peels. Limonene, a terpene, constitutes about 90% of crude citrus oil, and is purified from the oil by steam distillation. Linalool, a terpene alcohol, is found in small quantities in citrus peel and in over 200 other herbs, flowers, fruits, and woods. Terpenes and terpene alcohols are among the major components of many plant volatiles or essential oils. Other components of essential oils are ketones, aldehydes, esters, and various alcohols. Essential oils are the volatile compounds responsible for most of the tastes and scents of plants. Many of the essential oils also have some physiological activity.

Target pests: Caterpillars, cabbage worms, aphids, white flies

Mode of action. The modes of action of limonene and linalool in insects are not fully understood. Limonene is thought to cause an increase in the spontaneous activity of sensory nerves. This heightened activity sends spurious information to motor nerves and results in twitching, lack of coordination, and convulsions. The central nervous system may also be affected, resulting in additional stimulation of motor nerves. Massive over stimulation of motor nerves leads to rapid knockdown paralysis. Adult fleas and other insects may recover from knockdown, however, unless limonene is synergized by PBO. Linalool is also synergized by PBO. Little has been published regarding the mode of action of linalool in insects.

Mammalian toxicity. Both limonene and linalool were granted GRAS (Generally Regarded As Safe) status by the United States Food and Drug Administration in 1965, and are used extensively as flavorings and scents in foods, cosmetics, soaps, and perfumes. Both compounds are considered safe when used for these purposes because they have low oral and dermal toxicities. At higher concentrations, however, limonene and linalool are physiologically active and may be irritating or toxic to mammals. When applied topically, limonene is irritating to skin, eyes, and mucous membranes. Both limonene and linalool may be allergenic. Limonene acts as a topical vasodilator and a skin sensitizer; it was also shown to promote tumor formation in mouse skin that had been previously sensitized to tumor initiation. Linalool is more active as a systemic toxin than as a skin irritant. Both compounds affect the central nervous system, and moderate to high doses applied topically to cats and other laboratory animals cause tremors, excess salivation, lack of coordination, and muscle weakness. Even at the higher doses, however, these symptoms are temporary (lasting several hours to several days), and animals recover fully. Some cats may experience minor tremors and excess salivation for up to one hour after applications of limonene or linalool at recommended rates. Crude citrus peel oils and products prepared with the crude oils may be more toxic to animals than products containing purified limonene or linalool. Adequate research on the toxicity of crude citrus oils has not been conducted, and they are not recommended for use on animals.

3.3.8. Other Essential Plant Oils: Herbal Repellents and Insecticides

Essential oils are volatile, odorous oils derived from plant sources. Although they are used mainly as flavorings and fragrances in foods, cosmetics, soaps, and perfumes, some of them also have insect repellent or insecticidal properties. Many essential oils have GRAS (Generally Regarded As Safe) status; however, when applied topically at high concentrations they tend to be irritating to skin and mucous membranes. They are sometimes used as topical counterirritant to relieve or mask pain. Many of the essential oils that have low dermal toxicity may be toxic by ingestion. The most common essential oils used as repellents are the oils of cedar, lavender, eucalytus, pennyroyal, and citronella. They are used mostly on pets and humans to repel fleas and mosquitoes. With the exception of pennyroyal, these essential oils are thought to pose little risk to people or pets, though they should not be used above recommended rates. Some herbal pest products that contain essential oils recommend use daily or “as often as needed.” These products should be used moderately and with careful observation of the pet to spot early signs of skin irritation or possible toxic effects. Oil of pennyroyal contains pulegone, a potent toxin that can cause death in humans at doses as low as one tablespoon when ingested. At lower internal doses it may cause abortion, liver damage, and renal failure. Although the dermal toxicity of pennyroyal is fairly low, some cats are susceptible to poisoning by topical application of oil of pennyroyal, possibly because they ingest it during grooming. Citronella is sold mainly in the form of candles to be burned outdoors to repel mosquitoes from back yards or other small areas. It is also contained in some “natural” mosquito repellent lotions. Before the development of synthetic repellents, citronella was the most effective mosquito repellent available. Despite its wide usage, there is little scientific information available regarding its efficacy or mammalian toxicity.

UNIT. IV: NATURAL ENEMIES

Definition: The **predator** is **defined** as “an animal which feeds upon other animals (prey) that are usually smaller and weaker than it, frequently devouring them completely and rapidly. A predator most often is required to suck but an attack more than one prey to reach maturity.

Eg: Dragonflies and Damselflies (adults and aquatic nymphs), Praying Mantids, Some True Bugs (Hemiptera) are very effective predators. Examples are: ambush bugs, damsel bugs, leaf bugs, leaf - footed bugs, stink bugs (particularly spined soldier bugs), assassin bugs, and water striders. Dobsonfly larvae (in water), Snake flies, Lacewings and ant lions (immature), Many beetles, such as ladybugs, fireflies, ground, tiger, and rove beetles. In some species, the larvae are also predatory.

Distinguishing Characteristic of an Insect Predator:

1. Generally it consumes more than one host individual.
2. Most insect predators move around freely in both their immature and adult stages while searching for and feeding on their prey.
3. Though many of the predators are larger than their prey, in some instances adult parasitoids may act like insect predators by feeding on and killing the host.
4. Predatory insects feed on all host stages like egg, larvae or caterpillars, pupae and adult.

Lady beetles (Coccinellidae, also called ladybugs or ladybird beetles).

With their shiny, half-dome bodies and active searching behavior, lady beetles are among the most visible and best known beneficial insects. More than 450 native or introduced species have been found in North America. They are easily recognized by their red or orange color with black markings, although some are black with red markings and others have no markings at all. Lady beetles have been used in biological control programs for more than a century and are beneficial both as adults and larvae. Most larvae are blue-black and orange and shaped like little alligators. Young larvae pierce their prey and suck out their contents. Older larvae and adults chew entire aphids.

Any crop prone to aphid infestation will benefit from lady beetles, even though this predator’s vision is so poor that it almost has to touch an aphid to detect it. Growers of vegetables, grains, legumes, strawberries and orchard crops have all found lady beetles helpful in managing aphids. In its lifetime, a single beetle can eat more than 5,000 aphids. In the Great Plains, studies of greenbug pests in grain sorghum have shown that each lady beetle adult can consume almost one of these aphids per minute and dislodge three to five times that many from the plant, exposing the dislodged greenbugs to ground-dwelling predators. While their primary diet is aphids, lady beetles can make do with pollen, nectar and many other types of prey, including young ladybugs. Indeed, their extensive prey range — which includes moth eggs, beetle eggs, mites, thrips and other small insects — makes lady beetles particularly valuable as natural enemies.

Lacewings (*Chrysoperla* spp.)

Green lacewings — with their slender, pale-green bodies, large gauze-like wings and long antennae — are very common in aphid-infested crops, including cotton, sweet corn, potatoes, tomatoes, peppers, eggplants, asparagus, leafy greens, apples, strawberries and cole crops. The delicate, fluttering adults feed only on nectar, pollen and aphid honeydew. About 0.5 to 0.8 inches (12–20 mm) long, they are active fliers — particularly during the evening and night, when their jewel-like golden eyes often reveal their presence around lights. The larvae — tiny gray or brown "alligators" whose mouthparts resemble ice tongs — are active predators and can be cannibalistic. Indeed, green lacewing females suspend their oval eggs singly at the ends of long silken stalks to protect them from hatching siblings. Commonly called aphid lions, lacewing larvae have well-developed legs with which to lunge at their prey and long, sickle-shaped jaws they use to puncture them and inject paralyzing venom. They grow from less than 0.04 inch to between 0.2 and 0.3 inches (from <1 mm to 6–8 mm), thriving on several species of aphids as well as on thrips, whiteflies and spider mites — especially red mites. They will journey up to 100 feet in search of food and can destroy as many as 200 aphids or other prey per week. They also suck down the eggs of leafhoppers, moths and leafminers and reportedly attack small caterpillars, beetle larvae and the tobacco budworm.

Parasite: A parasite is an organism that lives at the expense of another organism - the host. In general, parasites share the following features:

- Parasites are usually smaller than their host.
- Parasites use both invertebrate and vertebrate hosts.

- Adult parasites may live on the host (e.g. lice), in the host (e.g. tapeworms) or feed on a host occasionally (e.g. mosquitoes).
- Parasites generally do not kill the host but may harm the host indirectly by spreading pathogens. This may affect the host's behaviour, metabolism or its reproductive activity.
- Many parasites have hooks, claws or suckers to attach to their host.
- Generally parasites have either a sucker (e.g. leeches) or piercing and sucking type mouthparts (e.g. fleas) for feeding.
- Both adults and young can be parasitic. In some cases the young are parasites but the adult is not.

Parasitoids: A parasitoid is an organism that has young that develop on or within another organism (the host), eventually killing it. Parasitoids have characteristics of both predators and parasites. Parasitoids include species of wasps, flies (e.g. tachinid flies), beetles and worms (e.g. gordian worms). In general, parasitoids share the following features:

- Parasitoids are usually smaller than their selected host.
- Parasitoids are very selective and only attack a particular life stage of one or several closely related species.
- Adult parasitoids are generally either nectar feeders or predators.
- Only female parasitoids are involved in finding and using the host.
- Generally the host does not die until the young are fully grown and ready to become adults.
- Parasitoids can sometimes prevent larval hosts (e.g. caterpillars) from developing, until the parasitoid is fully developed.

Classification of Parasitoids on the Basis of Parasitoid - Host and Parasitoid – Parasitoid Relationships

I) Number of Individuals/hosts:

a) Solitary Parasitoids: One progeny alone is capable of competing the development in or its host e.g. Chelonus blackdurni on PTM.

b) Gregarious Parasitoid: Several progeny are capable of completing their development in or on a single host e.g. Copidosoma koehleri on PTM. This may includes the parasitoid that deposits one or very few eggs in their host from which develops hundreads or thousands of progeny. These are polymbryonic species e.g. Braconid, Macrocentrus gifuensis on European corn borer.

II) Site of Attacks on Host Body:

a) Ectoparasitoids: An insect parasite which feed externally on the host body and complete their development externally on its host e.g. Bracon brevicorni.

b) Endoparasitoid: Parasitoids which complete their development within or inside their host body e.g. Chelonus blackburni. Endoparasitoid of aphids frequently emerge through a flap cut in the host abdomen.

III) Food Web Relationships:

a. Primary Parasitoids: The form of parasitism in which the attacking organism that develop itself in or upon the host which is non-parasitic e.g. on introduced pine saw fly parasitoids of a primary nature from hypmenoptrous and Dipterous species.

b. Secondary Parasitoids: The parasitoids develop itself in or on the host that are primary parasitoid.

c. Tertiary Parasitoids: The parasitoid develops itself in or on the host which is already secondary parasitoid. e.g. The parasitoid Tetrastichus coerulescens parasitic on secondary parasitoid Hybrocytus spp. and the primary saw fly parasitoid Itoplectis conquisitor.

d. Quaternary Parasitoids: Form of hyperprasitism in which the parasitic establish itself in/or the tertiary parasitoid.

IV) No. of Hosts Attacked:

a) Monophagous: The parasitoids which are specific to one particular host e.g. The icheumonid parasitoid, Mesolicus tenthredinis is a specific for saw fly.

b) Oligophagous or Stenophagous: Those parasitoids that restrict themselves to vary few and often closely related hosts, e.g. Exerterus amictoriius is an ichneumonid parasitoid of saw fly in the genera Diprion and Neodiprion.

c) Polyphagous: Those parasitoids that maintain themselves on a multiple of hosts, e.g. Compsilura concinnata a tachinid introduced against gypsy moth has been recorded from close to 20 hosts.

V) No. of Host individuals Essential for Attack:

a) Heteroxenous: Many of oligo and polyphagous parasitoid species requiring alternating of hosts to complete several generations each year, e.g. The tachinid, Ceromasla auricaudata which over winters in a host pupa of fall webworm normally attacks univoltine spruce budworm in the spring in Canada.

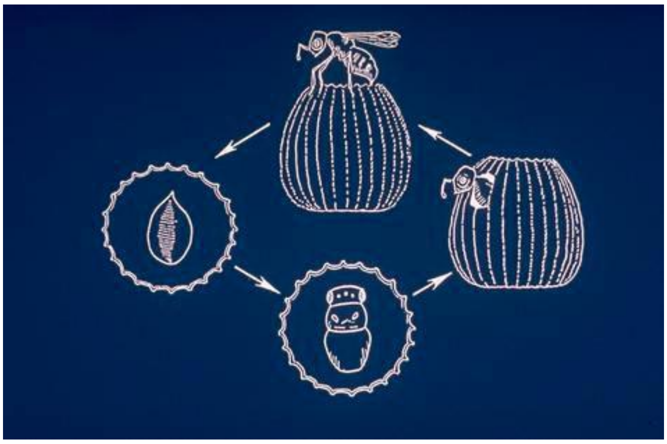
b) Monoxenous: The parasitoids those require only one host species for development, e.g. *Exenterus amictorius* a parasitoid on the introduced pine saw fly and the Drino bohemica, a lachinid parasitoid of European spruce sawfly.

Trichogramma

Phylum: Arthropoda **Class:** Insecta **Order:** Hymenoptera **Family:** Trichogrammatidae

Common hosts: Eggs of hundreds of species of insects, especially moths, butterflies, and sawflies. Especially important in management of codling moth and fruitworm. A few species parasitize eggs of beetles, flies, true bugs, other wasps, and lacewings.

Commercially available: Several species are commercially available



Adults are approximately 1/25 inch (1 mm) or less—the size of a period at the end of a sentence. They often have wing hairs (setae) arranged in rows. Their body is relatively compact and the antennae are short. *Trichogramma* species are difficult to identify due to their minute size and generally uniform morphological features. *Trichogramma* spp. undergo complete metamorphosis. The adult wasp lays an egg within a recently laid host egg, and as the wasp larva develops, it eats the host embryo, causing the egg to turn black. Because their life cycle from egg to adult is about 7 to 10 days, these parasites have many more generations than their hosts, and their populations can increase rapidly. *Trichogramma* turns the eggs of some caterpillar species black. This is the best way to detect parasitization by *Trichogramma*.

Advantages & Disadvantages of Biological Control

Controlling pests with their natural enemies, including parasites, predators, diseases and competing organisms, is called biological control. It is an alternative to using broad-spectrum pesticides, which kill off beneficial insects as well as pest organisms. To choose a successful biological control program, it is crucial to identify the pest along with its population levels and the circumstances of the infestation.

Minimized Safety Concerns: Unlike chemical pesticides, biological control agents, also called bioagents, leave behind no long-lasting residues that remain in the environment. They don't leach into groundwater or create resistant strains of insects. Biological control minimizes environmental, legal and public safety concerns. Integrated pest control uses bioagents in combination with other measures.

Increased Selectivity: Often a host-parasite or prey-predator relationship is a specific one that doesn't affect other organisms -- a benefit for the environment. For instance, when using nematodes for insect control, it's important to use the correct species for the insect you want to control. Biological-control nematodes aren't parasitic on their host. They enter the insect through a natural body opening and then eat a bacteria they carry with them that multiplies inside the host. Nematodes have to be the right size to enter the particular insect and must have behavior that allows contact with the insect to begin with.

Cost Considerations: Biological control can either be less or more expensive than pesticides. You can incur significant expense studying, choosing, testing and breeding a bioagent. However, in cases in which bioagents are applied to low-level pest populations, pest control can be long-term and inexpensive. Some fungi attack insects and kill them. A fungal spore penetrates the insect and grows throughout it. It takes about a week for the insect to die. Fungi are cost-effective unless a high application rate is needed for heavy insect infestations.

Dedication of Time: Bioagents may act over several generations or more to successfully manage pest populations. The imported fire ant, a serious pest in the southern United States, is parasitized by a tiny phorid fly native to its South American range. When the phorid fly is bred and released into the imported fire ant's U.S. range, less than 3 to 4 percent of the ants in a colony become infected. The effect of phorid flies on imported fire ant colonies could take years to become evident.

Skill Level: It may be more difficult for a nonprofessional to accomplish biological control given the many variables involved and the specialized knowledge of pests, bioagents and environmental conditions often needed for success. For instance, microbial pathogens are most effective when young caterpillars are feeding. In Hawaii, it took two kinds of parasitic wasps, an egg parasitoid and a parasite of the larvae, to successfully control the banana skipper -- a moth larva that damages banana leaves.

New Pests: Sometimes when a non-native bioagent is introduced to control a non-native pest species, it, in turn, becomes a pest. The multicolored Asian lady beetle was introduced into the United States for control of aphids. It became a pest insect that invades homes for overwintering. In Hawaii, the small Indian mongoose was introduced to control snakes and rats in sugarcane fields. It also preys on native Hawaiian birds, amphibians, reptiles and poultry. About $50 million in annual damages in Hawaii and Puerto Rico result from mongoose depredation. Modern methods greatly lessen the possibility of introducing harmful species.

UNIT. V. SEMIOCHEMICALS

Allelochemicals: A chemical produced by a living organism that exerts a detrimental physiological effect on individuals of another species when released into the environment. Allelochemicals are released into the environment by plant organs such as roots, rhizomes, leaves, stems, bark, flowers, fruits and seeds. Allelochemicals can be classified into 10 categories according to their different structures and properties: 1. water-soluble organic acids, straight-chain alcohols, aliphatic aldehydes, and ketones; 2. simple lactones; 3. long-chain fatty acids and polyacetylenes; 4. quinines (benzoquinone, anthraquinone and complex quinines); 5. phenolics; 6.cinnamic acid and its derivatives; 7. coumarins; 8.flavonoids; 9. tannins; 10. steroids and terpenoids (sesquiterpene lactones, diterpenes, and triterpenoids). Allelochemicals can be further classified based on whether they favour the receiver (kairomones), or the sender (allomones).

Kairomones: A kairomone is an interspecific semiochemical or a mixture of semiochemicals, produced by one species which induces responses advantageous to an individual of a different species perceiving the signal. Kairomones are important in biological control efforts due tothe fundamental importance of semiochemicals in phytophagous insect host-plant selection and the potential for natural enemies to employ these as well as host insect odors in searching effectively for prey. It has been understood since the 1960s that herbivores in natural ecosystems are limited, not so much by food supply, but rather by natural enemies i.e., by biological control. Because kairomones play an important role in limiting herbivore populations in natural ecosystems, especially in tropical areas, they may also have considerable utility for human management of insect crop pests.

Volatiles emitted from the host plants on which herbivores feed have been demonstrated in many studies to serve as kairomonal signals, attracting beneficial entomophages to the host plant, after which they employ other semiochemical and visual cues to search efficiently for different life stages of the plant pests. For example, parasitization by *Trichogramma chilonis* (Hymenoptera: Trichogrammatidae) on eggs of *Helicoverpa armigera* (Lepidoptera: Noctuidae) is high when the eggs are present on tomato rather than other crops. Host insects also emit kairomones attractive to beneficial entomophages. Tricosane, present in wing scales of *Helicoverpa zea* acts as a host-insect-derived kairomone attractive to *Trichogramma evanescens.*

Major chemical constitutions present in the kairomone:

A. Terpenes and Flavanoids 1. Isoprene 2. a-pinene 3. b-pinene 4. D3 -carene 5. Limonene 6. Camphene 7. Myrcence 8. b-phellandrene 9. Sabinene 10. a-terpinene 11. Ocimene 12. Terpinolene 13. g-terpinene 14. Flavones 15. Flavonols 16. Flavanones 17. Flavanonols 18. Flavanols 19. Anthovyanidins 20. 21. Isoflavones 22. Neoflavonoids 23. Chalcones.

B. Terpinoids 1. Geraniol 2. Eugenol 3. Citronellol 4. Linalool 5. Terpineol 6. Menthol 7. Menthone 8. Carvone 9. b-Pinene 10. Cineole 11. Carvacrol 12. Thymol 13. b-Caryophyllene.

C. Saturated hydrocarbons 1. Decane 2. Tridecane 3. Tetradecane 4. Pentadecane 5. Octadecane 6. Heneicosane 7. Eicosane, 8. Tricosane 9. Petacosane 10. Hexacosane 11. Octacosane 12. Nonadecane 13. Docosane, 14. Tetratriacontane 15. Hexatriacontane 16. Dotriacontane 17. Tritetracontane 18. Tetratetracontane, 19. Hexadecanoic acid.

Allomones : Allomones benefit the producer by modifying the behavior of the receiver although having a neutral effect on the receiver. Allomones are chemicals that benefit the producer but have neutral effects on the recipient. For example, defensive and/or repellent chemicals are allomones that advertise distastefulness and protect the producer from lethal experiment by prospective predators. The effect on a potential predator is considered to be neutral, as it is warned from wasting energy in seeking a distasteful meal. The worldwide beetle family Lycidae has many distasteful and warning-colored (aposematic) members, including species of *Metriorrhynchus* that are protected by odorous alkylpyrazine allomones. In Australia, several distantly related beetle families include many mimics that are modeled visually on *Metriorrhynchus*. Some mimics are remarkably convergent in color and distasteful chemicals, and possess nearly identical alkylpyrazines. Others share the allomones but differ in distasteful chemicals, whereas some have the warning chemical but appear to lack distastefulness. Other insect mimicry complexes involve allomones.

Some defensive allomones can have a dual function as sex pheromones. Examples include chemicals from the defensive glands of various Heteropteran bugs, grasshoppers, and beetles (Staphylinidae), as well as plant-derived toxins used by some Lepidoptera.

Many female ants, bees, and wasps have exploited the secretions of the glands associated with their sting — the poison (or venom) gland and Dufour's gland — as male attractants and releasers of male sexual activity. A novel use of allomones occurs in certain orchids, whose flowers produce similar odors to female sex pheromone of the wasp or bee species that acts as their specific pollinator. Male wasps or bees are deceived by this chemical mimicry and also by the color and shape of the flower, with which they attempt to copulate. Thus the orchid's odor acts as an allomone beneficial to the plant by attracting its specific pollinator, whereas the effect on the male insects is near neutral — at most they waste time and effort.

Synomones benefit both the producer and the receiver. This terminology has to be applied in the context of the specific behavior induced in the recipient. The terpenes produced by damaged pines are kairomones for pest beetles, but if identical chemicals are used by beneficial parasitoids to locate and attack the bark beetles, the terpenes are acting as synomones (by benefiting both the producer and the receiver). Thus α-pinene and myrcene produced by damaged pines are kairomones for species of *Dendroctonus* but synomones for pteromalid hymenopterans that parasitize these timber beetles. In like manner, α-cubebene produced by Dutch elm fungus is a synomone for the braconid hymenopteran parasitoids of elm bark beetles (for which it is a kairomone).

An insect parasitoid may respond to host-plant odor directly, like the phytophage it seeks to parasitize, but this means of searching cannot guarantee the parasitoid that the phytophage host is actually present. There is a greater chance of success for the parasitoid if it can identify and respond to the specific plant chemical defenses that the phytophage provokes. If an insect-damaged host plant produced a repellent odor, such as a volatile terpenoid, then the chemical could act as: an allomone that deters non-specialist phytophages; a kairomone that attracts a specialist phytophage and a synomone that lures the parasitoid of the phytophage.

Pheromones : Insect pheromones are volatile organic molecules of low molecular weight that elicit a behavioural response from individuals of the same species and can be used to communicate between members of the same or the opposite sex. Pheromones are generally produced by specialized exocrine glands associated with the cuticle. It was suggested that biosynthesis of aggregation pheromone occurred in the gut tissue. The production and release of insect pheromones is governed by a variety of environmental factors and physiological mechanisms. Furthermore, the amount of pheromones that insects release is extremely low and varies from a few nanograms to micrograms per unit of time, depending on the species. For example, it was reported that the release rate of the main pheromonal component in the agave weevil, *Scyphophorus acupunctatus*, was between 0.2 and 2.1 ng/24 h. Factors that may have an impact on the release of pheromones include circadian rhythm, temperature, presence of food sources, and age of the insects.

Chemoreceptor cells present in the exoskeleton of insects, also called sensilla, mediate the perception of pheromones present in the environment. For example, sensilla found in insect antennae and palps contain pheromone receptive olfactory receptor neurons (ORNs). The ability to detect different pheromones or physiological specificity is determined by receptor proteins present in the ORNs. The effectiveness of pheromones in insect communication is affected by multiple factors including chemical nature, volatility, solubility, and persistence in the environment. Pheromones modulate critical activities such as mate and host location in insects and are primarily classified on the basis of their effects.

Types of Insect Pheromones: Pheromones are subdivided into several types based on the nature of the interactions between emitters and receivers. Furthermore, releaser pheromones (e.g. alarm pheromone) bring about immediate changes in the behaviour of receivers whereas primer pheromones (e.g. 9-keto-2-decenoic acid or queen honeybee substance) cause relatively slow and longerterm physiological changes.

Sex Pheromones: Sex pheromones act as a signal to attract potential mates over long distances (e.g. moths). Sensitive chemoreceptive sensilla in insects facilitate the detection of very low concentrations of sex pheromones in the environment. Release of sex pheromones may be governed by factors such as time of day, weather, and the availability of host plants. Furthermore, both the immature and adult stages of insects can sequester chemicals from host plants and use them as precursors for sex pheromones.

Alarm Pheromones: Some insects (e.g. aphids) release alarm pheromones in response to attack by natural enemies. Alarm pheromones serve as a trigger for dispersal and avoidance behaviour among the conspecifics. However, some social insects may respond aggressively to alarm pheromones (e.g. bees in genus Apis and leaf-cutting ants).

Aggregation Pheromones: These can be defined as intraspecific signals that facilitate group formation and mating at a food source. For example, aggregation pheromones released by some species of bark beetles result in the recruitment of other individuals of either sex to the feeding site.

Anti-Aggregation Pheromones: These compounds result in the dispersal of individuals (both sexes) and help maintain optimum spacing in a resource-limited environment.

Oviposition-Deterring or Epideictic Pheromones: These compounds help females of certain insect species avoid egg deposition on hosts that have already been utilized by conspecifics and thus reduce intraspecific competition. Females of numerous species of fruit flies deposit an oviposition-deterring fruit-marking pheromone during ovipositor dragging after egglaying. Similarly, pepper weevil, females deposit an oviposition plug that deters egg-laying.

Trail Pheromones: Social insects (e.g. ants and termites) use trail pheromones to mark feeding or nest sites to guide members of their colony.

Pheromone trap

A **pheromone trap** is a type of insect trap that uses pheromones to lure insects. Sex pheromones and aggregating pheromones are the most common types used. A pheromone-impregnated lure, as the red rubber septa in the picture, is encased in a conventional trap such as a bottle trap, Delta trap, water-pan trap, or funnel trap. Pheromone traps are used both to count insect populations by sampling, and to trap pests such as clothes moths to destroy them. A pheromone-impregnated **lure**, as the red rubber septa in the picture, is encased in a conventional trap such as a **bottle** trap, Delta trap, **water**-pan trap, or funnel trap. Pheromone traps are used both to count **insect** populations by sampling, and to trap pests such as clothes moths to destroy them.

Biological role of pheromones: There are three main uses of pheromones in the integrated pest management (IPM) of insects. The most important application is in monitoring a population of insects to determine if they are present or absent in an area or to determine if enough insects are present to warrant a costly treatment. This monitoring function is the keystone of integrated pest management. Monitoring is used extensively in urban pest control of cockroaches, in the management of stored grain pests in warehouses or distribution centers, and to track the nationwide spread of certain major pests such as the gypsy moth, Medfly, and the Japanese beetle. With major increases in worldwide trade, exotic pests are being brought into ports of entry in cargo containers and packing materials (ship dunnage). Sometimes containers from ships are transferred uninspected to semi-trailers and trucked far inland. When the containers are opened and packaging materials are removed, the exotic insect pests are able to disperse without the usual level of scrutiny provided at ports of entry. Pheromone traps are currently in use to monitor the movement of such exotic insect pests into most major North American ports of entry.

A second major use of pheromones is to mass trap insects to remove large numbers of insects from the breeding and feeding population. Massive reductions in the population density of pest insects ultimately help to protect resources such as food or fiber for human use. Mass trapping has been explored with pine bark beetles and has resulted in millions of insects attracted specifically into traps and away from trees. Relatives of bark beetles called ambrosia beetles have been mass trapped from log sorting and timber processing areas throughout British Columbia. These trapping operations have reduced damage to the wood in raw logs and newly cut boards. Mass trapping has also been used successfully against the codling moth, a serious pest of apples and pears. Another common example of mass trapping involves yellow jackets, which can become bothersome at the end of the summer season. However, mass trapping of yellow jackets in colorful yellow -green traps is carried out with a food attractant, rather than a pheromone bait. A third major application of pheromones is in the disruption of mating in populations of insects. This has been most effectively used with agriculturally important moth pests. In this scenario, synthetic pheromone is dispersed into crops and the false odor plumes attract males away from females that are waiting to mate. This causes a reduction of mating, and thus reduces the population density of the pests. In some cases, the effect has been so great that the pests have been locally eradicated.

Kairomones : Kairomones are interspecific chemical communication substances of animals, bringing benefit to the recipients of the chemical signal. The ability to perceive and distinguish chemical cues has been studied in various organisms.

Applications: Like pheromones (communication chemicals used within a species), kairomones can be utilized as an 'attracticide' to lure a pest species to a location containing pesticide. However, they might also be used to lure desired species. Kairomones produced by the hosts of parasitic wasps have been used in an attempt to attract them and keep them around in crops where they reduce herbivory, but this could instead result in fewer attacks on the herbivous pest if the applied kairomone distracts them from finding real hosts. For example, studies have shown that kairomones are effective in attracting female African sugarcane borers to deposit eggs on dead leaf material.

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