ISBN: 978-81-19149-94-0

9. Modern Techniques of Pest Management

Swati Priya

Ph.D. Research Scholar,
ICFRE-Eco-rehabilitation Centre,
Prayagraj, UP.

Komal Bhatt

Ph.D. Research Scholar,
Jawaharlal Nehru Krishi Vishwa Vidyalaya,
Jabalpur, MP.

Mukul Anand Ray

Ph.D. Research Scholar,
ICFRE- Tropical Forest Research Institute,
Jabalpur, MP.

Supriya

Ph.D. Research Scholar,
ICAR-National Dairy Research Institute,
Karnal, Haryana.

Abstract:

Insect pest concerns have traditionally plagued agriculture. As subsistence farming produced little and generally had a large insect population. Therefore, agriculture has to be enhanced due to the dramatically increased human population during the previous century. This was accomplished through the application of new agricultural technology, including the creation of novel irrigation systems that provide more irrigation, the use of high-nitrogen fertilizers, the cultivation of new crops, the introduction of improved and exotic cultivars and excessive pesticide applications that regularly result in the resurgence of pests because they killed the natural enemies. Both crop yields and severe insect pest outbreaks in agricultural crops have grown due to contemporary technologies. Pest have not only affected the crops but the chemical pesticide used for exterminating the pest population has been proven injurious to human and led to financial losses worldwide. The importance of pest management through and natural insect predators is highlighted, along with a thorough explanation of the concepts of eco-friendly pest control. A diversity of environmental friendly methods, including organic pesticides, resistant crop types, biological, cultural, mechanical, physical and behavioural controls, as well as those that are supported by successful case studies are described. The analysis of new developments in eco-friendly pest control emphasizes the critical importance of policy and education in promoting its adoption as it looks at developing trends and technology in this area. The *chapter promotes a change from conventional methods to more sustainable ones, which are essential for agricultural sustainability and environmental preservation.*

Keywords:

Pest management, Trap crop, sanitation, Pheromones

9.1 Introduction:

Agriculture has been negatively impacted by several pests such as insects, weeds, plant infections and nematodes from time immemorial, resulting in an estimated 45% crop loss equivalent to about 290 billion each year (Aneja *et al.*, 2016). Pests and diseases are a major cause of agricultural losses regardless of the strategies adopted. Weeds, insects and diseases reduce plant density, stunted plant growth which eventually depletes food production. Although traditional chemical pesticides have increased food production, they have also had a negative impact on the ecosystem and non-target creatures. To prevent and reduce crop losses caused by pests in the field (pre-harvest losses) and during storage (post-harvest losses), a number of crop protection measures have been developed. In recent decades, chemical pesticides have been utilized to minimize food losses due to insect pests, which also resulted in the losses of agricultural productivity. Furthermore, volatile pesticide residues have occasionally created food safety concerns among domestic consumers and posed trade barriers for export crops. Pests may suffer biological or physical harm from the insecticides. Some pesticides are sprayed or administered indirectly on a plant that an insect might eat. Due to the adverse effects of pesticides on the environment as well as the soil and human health, stricter standards and laws are being imposed on their application. There is a dire need for new products and technology that will help manage and prevent pests. Fortunately, technological advancements in modern agriculture have led to a wide range of options like biological control, microbial pesticides, pest behaviour, genetic modification and plant immunization of pest population.

Table 9.1: List of Methods of Pest Management

Methods	Functions
Cultural Control	Agricultural practices and techniques to manage pests without relying heavily on synthetic pesticides. By creating unfavourable conditions for pests, disrupting their life cycles and promoting a healthy ecosystem
Biological Control	Natural enemies (predators, parasites and pathogen) suppress pest populations
Microbial Pesticides	Combinations of microbes that, by the production of contaminants, illnesses, the prevention of the development of other microbes, or other means, control pests
Pest Behaviour-Modifying Chemicals	Utilizing chemical signals produced by living things to cause certain responses in other creatures
Plant Immunization	Enhancing plant pest resistance without using breeding or genetic engineering

9.2 Cultural Control:

A growing interest in cultural approaches of pest management has been sparked by the need for pest control strategies that are economical, effective and environmentally responsible. Pest control must take into account cultural practises, or the techniques and methods farmers employ in their regular farming operations. The reduction of insect infestations can be considerably aided by their alteration. Examples of practices that can interrupt the life cycle of pests and lessen their impact include crop rotation, intercropping, utilizing pest-resistant cultivars, timely planting and good cleanliness. Changing conventional practices may entail utilizing pest-free seeds or transplants, altering planting dates to prevent pest populations at their height and managing crop residues properly. All of these adjustments may result in healthier crops that are less vulnerable to insect infestations, increasing yield while reducing environmental impact.

Advantages of Cultural Practices:

a. Obstacles to agricultural infestation by pests
b. The establishment of unfavourable biotic circumstances that decrease the pest's ability to survive as individuals or colonies.
c. Crop modification in such a manner that insect infestation results in less crop harm
d. Environmental manipulation to strengthen natural enemies

9.2.1 Nutrient Management:

Nutrient management, by improving plant health and resistance, indirectly controls insect pests. The need for balanced fertilization, avoiding nutrient overload and timing nutrient delivery cannot be emphasized. Plants can suffer from nutrient deficits, making them more vulnerable to insect pests. Plants should be monitored for indicators of nutrient deficits and treated as soon as possible with proper fertilization. Plants defence systems against pests can be strengthened by ensuring appropriate nutrition levels. Organic matter management, correcting nutritional deficits as soon as possible and encouraging crop diversification and rotation are also advantageous. Nutrient management must be integrated with other pest control measures for efficient pest management. Overall, optimizing nutrition levels strengthens plant defences and minimizes insect vulnerability.

9.2.2 Irrigation Management:

Irrigation plays a crucial role in pest management by influencing pest populations and promoting plant health. Proper irrigation practices are essential for maintaining optimal plant growth and reducing plant stress, which in turn strengthens plants' natural defence mechanisms against pests. Additionally, irrigation can directly impact pest habitats and survival, making it a valuable tool for manipulating pest populations. When plants are stressed due to insufficient water supply, they become more vulnerable to pest infestations. By providing adequate and timely irrigation, farmers can ensure that plants have the necessary moisture to thrive, reducing their susceptibility to pests. Well-hydrated plants are generally healthier and better equipped to withstand pest attacks, leading to more resilient crops. The timing of irrigation is another crucial factor in pest management. Some pests exhibit specific activity patterns during the day or in response to moisture availability. By adjusting the timing of irrigation to periods when pests are less active, farmers can minimize pest damage. By implementing irrigation strategies that prevent waterlogging or excessive soil moisture, farmers can create less favourable habitats for these pests. By depriving pests of their preferred environments, farmers can limit their population growth and reduce the risk of infestations.

This strategic approach optimizes water use efficiency while reducing the opportunities for pests to thrive and cause harm. Irrigation can also be utilized as a cultural control measure. For instance, strong sprays of water during irrigation can dislodge pests like aphids or spider mites from plants. This mechanical method helps reduce pest populations without relying solely on chemical pesticides, promoting a more environmentally friendly approach to pest management.

9.2.3 Crop Rotation/Intercropping:

Crop rotation, which involves cultivating multiple crops in the same place in an interval of several seasons, is an effective pest management technique. It disrupts the pest life cycle, degrading the habitat for pests that are unique to particular crops. The number of the pests is kept in check by not consistently providing them with their favoured host. Because various crops have distinct nutrient needs and provide diverse contributions to the health of the soil, crop rotation improves soil fertility and structure.

By supporting the crops' natural defences against pests and diseases, this practise indirectly boosts agricultural yields. To prevent damage from *A. soccata*, *S. sorghicola* and *Calocoris angustatus* (Leth.), sorghum is typically cycled with cotton, peanuts, sunflower, or sugarcane (Sharma 1985). Sorghum and pigeon pea can be intercropped to lessen *H. armigera* damage to the pigeon pea (Hegde and Lingappa 1996). A well-chosen cropping strategy (intercropping or mixed cropping) can be utilized to lessen the risk associated with monocultures and/or reduce insect occurrence.

9.2.4 Companion Planting:

Companion planting is a cultural practice where particular plant species are planted next to crops that are prone to insects in order to repel or prevent them. This technique makes use of some plants' inherent advantages and characteristics that serve as natural insect repellents. Farmers may construct a natural barrier that helps defend their crops from insect pests by carefully blending these plants with the main crop. When integrating companion plants into their field designs, farmers frequently run across logistical challenges.

For instance, producing different crops in the same area is not possible with modern agricultural methods and machinery (Tooker and Frank, 2012). Companion plants may also lower economic advantages and impair agricultural output (Letourneau *et al.* 2011; Lin, 2011). According to Beizhou *et al.,* 2011 observed an epidemic of secondary pests and a decline in output in an orchard environment. Reduced yields are frequently linked to improper companion plants competing for resources (Bone *et al.,* 2009). Pest-repellent properties of different companion plants:

Table 9.2: List of Widely Adopted Common Companion Crops.

Sr. No.	Crop	Properties
i.	Marigolds	Marigolds emit compounds with a strong scent that deters various insect pests such as aphids, nematodes and whiteflies. Their presence creates a natural barrier that protects nearby crops.
ii.	Nasturtiums	It serves as trap plant, attracting pests like aphids, whiteflies and squash bugs away from the main crop. They divert the attention of these pests, reducing their impact on the cultivated plants.
iii.	Basil	With its aromatic qualities, basil repels mosquitoes, flies and certain beetles. When planted alongside tomatoes, it helps deter pests that commonly affect tomato plants.
iv.	Garlic	Garlic possesses insect-repellent properties, especially against aphids, Japanese beetles and spider mites. By planting garlic near roses, cabbage, or fruit trees, farmers can protect these plants from pest infestations.
v.	Chives	Chives release compounds that repel aphids, carrot flies and various fruit tree pests. Planting chives near susceptible crops can effectively deter these insects.
vi.	Mint	Mint's strong scent acts as a deterrent for pests like ants, aphids and flea beetles. However, it's important to contain mint in isolated areas or containers to prevent it from spreading uncontrollably.
vii.	Sunflowers	Sunflowers attract beneficial insects such as ladybugs, lacewings and parasitic wasps. These predators prey on garden pests, enhancing biological pest control when planted near crops.
viii.	Lavender	Lavender is known for its pleasant aroma and ability to deter moths, fleas and flies. Placing lavender near crops susceptible to these pests can help keep them at bay.
ix.	Sunflowers	Sunflowers can attract beneficial insects like ladybugs and parasitic wasps, which prey on common garden pests like aphids and caterpillars. Planting sunflowers near susceptible crops can encourage these beneficial insects to stick around.
x.	Dill	Dill attracts beneficial insects like ladybugs and lacewings, which are voracious predators of aphids and other soft-bodied pests. Planting dill near susceptible crops can attract these helpful insects.

By strategically incorporating these companion plants into farming practices, farmers can create a natural defence system against insect pests. The diverse range of pest-repellent properties exhibited by these plants offers an environmentally friendly and sustainable approach to pest management. These are just a few examples of companion plants that can help repel or deter insects from crops. The specific companion plants chosen may vary depending on the region, the target pests and the crops being grown. It's important for farmers to research and experiment with companion planting to determine which combinations work best for their specific circumstances.

The frequency of pests can be considerably influenced by the timing of planting and harvesting. Changing the planting dates might help prevent peak pest activity since some pests may be more widespread during particular times. Likewise, timing the harvest correctly protects crops from being overexposed to pests, minimising possible harm. This method requires a thorough grasp of both the crop's development phases and the insect life cycle. With the right time, farmers may take advantage of pests' vulnerabilities while safeguarding the most delicate stages of crop development.

9.2.5 Trap Crops:

Pests are lured away from the main crop of interest by cultivating trap crops (Ratnadass *et al.,* 2012) certain illnesses are propagated by the insects that feed on the contaminated crops, or "vectors." Similar to this, several insect pests target economically significant agricultural plants, ultimately resulting in significant qualitative and quantitative losses. Taro cultivation proved successful in luring armyworms (*Spodoptera litura*) away from tobacco crops. However, it is crucial to note that taro plants should be planted 20 to 30 days prior to tobacco in order to effectively combat armyworm attacks, as the latter proved ineffective at luring the pest at the seedling stage (Zhou *et al.* 2010). To control the soybean cyst nematode in maize, soybean and pea were planted as trap crops. When sunflower, castor bean and okra were employed as trap crops for leafhoppers, the assault on cotton was greatly decreased. In another study, planting soybean as a trap crop more effectively decreased cotton boll damage and stink insect density than peanuts (Tillman *et al.,* 2015).

9.2.6 Sanitation and Hygiene Practices:

Agriculture pest management requires strict hygienic and sanitation procedures. By taking the right steps, farmers may control insect populations, avoid infestations and create a healthy environment. This entails swiftly removing crop leftovers, efficiently controlling weeds, using excellent waste management techniques and upholding sanitation and hygiene. Also crucial are proper water management and pest management for cattle. Monitoring insect populations and assessing the efficacy of management measures both benefits from record-keeping. Farmers may reduce their dependency on synthetic pesticides and embrace sustainable pest management methods by incorporating these practices.

9.2.7 Resistant Varieties:

Resistant varieties are plant varieties with inherent traits that make them less susceptible or tolerant to specific pests. They have built-in defences like physical barriers, chemical substances, or physiological characteristics. Utilizing resistant cultivars encourages sustainable pest control by reducing the need for chemical pesticides. The feeding, reproduction, or life cycle of pests is disrupted by resistant cultivars, which are unique to certain pests or groups of pests. Farmers may reduce pesticide use, adopt integrated pest management techniques and achieve more sustainable pest control by adding resistant types. New and better resistant cultivars will always be available because of breeding programmes' continuous progress. However, for full pest management, resistant types should be utilised in conjunction with other pest management techniques, as well as with monitoring and cultural interventions.

9.3 Biological Control:

The utilization of living organisms for reducing the negative effects of pests is referred is as biological control. Pests including insects, vertebrates, disease-casing microorganisms and weeds can all be controlled biologically, however, the techniques and organisms employed vary from each other. Knowledge of natural enemies is crucial for the reduction of pest populations. When insecticides have wiped out the natural adversaries of prospective bugs, this has been consistently shown. When insects are liberated from the care of their natural enemies, they frequently turn into destructive pests, even though they were previously of little economic value. On the other hand, when a non-toxic technique of eradicating a major pest is discovered, the need for pesticides is decreased and the survival of natural enemies' increases, which typically results in a decrease in the number of secondary pest species and the harm they cause.

The three categories of natural enemies of insect pests are:

a. Predators
b. Parasitoids
c. Pathogens

9.3.1 Predators:

Predators of many different species eat insects. Many vertebrates, including birds, amphibians, reptiles, fish and mammals, depend heavily on insects for food. These insectivorous vertebrates typically consume a wide variety of insect species and do not often concentrate on pests unless they are in large numbers. Because they consume a narrower variety of prey species and have shorter life cycles than other arthropod predators, insects and other arthropods are more frequently used in biological control. This is because their population density can alter in reaction to changes in the density of their prey. Lady beetles, ground beetles, rove beetles, flower bugs and other predatory true bugs, lacewings and hoverflies are a few significant insect predators. Insects, nuisance mite species and other arthropods are all preyed upon by spiders and some mite families.

9.3.2 Parasitoids:

Insects known as parasitoids have an immature stage that grows on or in a single insect host before killing it. The adults can be predators because they normally live on their own. Additionally, they might consume pollen, honeydew, or plant nectar as food sources. The host range of parasitoids is constrained and many are highly specialised, as they must adapt to the life cycle, physiology and defences of their hosts. Therefore, it is crucial to correctly identify the host and parasitoid species when utilising parasitoids for biological control.

9.3.3 Pathogens:

Like other animals and plants, insects can contract diseases from bacteria, fungus, protozoans and viruses. These illnesses may limit or prevent insect pests' ability to feed and grow, as well as their ability to reproduce. In addition, certain nematode species that cause sickness or death through their bacterial symbionts also prey on insects. Diseases can naturally spread across an insect population under specific climatic conditions, especially when the insect population density is high.

9.4 Microbial Pesticides:

Microbial pesticides, which are made up of bacteria, fungus, protozoans and viruses, are an environmentally benign alternative to chemical pesticides. The term "microbial pesticides" refers to specific classes of pesticides made from natural components like microbes. A better alternative to chemical pesticides is microbial pesticide. They are living organisms that can be utilised to manage pests that harm crop plants, such as natural enemies, their by-products, or microbial products. They are microbial insecticides based on pathogenic microorganisms that are particular to a target pest and provide an effective and environmentally friendly way to reduce pest issues. Due to their degradability and lack of leftover effects on people, they are safer for both the environment and human health. Microbial insecticides with pathogenic effects on target pests are frequently utilized. These include biofungicides (Trichoderma), microbial herbicides (Phytophthora) and microbial insecticides (*Bacillus thuringiensis*, *B. sphaericus*). Because the biopesticides frequently work in incredibly small doses and break down quickly, there are fewer exposures and less environmental issues.

Types of Microbial Pesticides:

These are effective and a good alternative to chemical pesticides. Microbial toxins are biological poisons produced by the microorganisms' bacteria or fungus. Only a few types of pests are harmful to these microorganisms. Microbial pesticides work by invading the stomach or integument of the insect, where they proliferate and kill the host, which in this case such as:

9.4.1 Bacteria:

There have been numerous attempts to develop microbial pesticides, such as *Bt*, which has been used commercially for more than 40 years (Gelernter and Schwab 1993). According to Revathi *et al.,* (2013), commercial Bacillus species such *Bacillus thuringiensis israelensis* Bti and *Bacillus sphaericus* 2362 (Bs) were found to be especially effective against mosquito and other dipteran larvae. Numerous bacterial species and subspecies, particularly Bacillus, Pseudomonas and others, have been proven to be effective microbial pesticides for controlling plant diseases and insect pests. The most notable of these are pesticides based on several *Bacillus thuringiensis* Berliner subspecies. These include *B. thuringiensis* species kurstaki and aizawai, which are extremely poisonous to lepidopteran larval species and *B. thuringiensis israelensis*, which has activity against mosquito larvae, black fly (simuliid) and fungus gnats. In order to prevent harm to non-target creatures, including people, microbial pesticides should be regularly monitored (Mazid *et al.,* 2011).

9.4.2 Fungi:

Pathogenic fungi, which can thrive in both terrestrial and aquatic ecosystems and are specifically connected with insects are known as entomopathogenic fungi, are another significant type of microbial pest management organisms (Khachatourians, 2009). They could be facultative or obligatory, commensals, or insect symbionts. Aphids, thrips, mealybugs, whiteflies, scale insects, mosquitoes and all sorts of mites are sucking insect pests that they infect and/or kill depending on the circumstances of contact (Barbara and Clewes 2003; Pineda *et al.,* 2007). Entomopathogenic fungi are promising microbial pesticides with several pathogenesis-related mechanisms.

Toxins that are effective against insects are also produced by several fungi, especially *Streptomycetes* (Dowd, 2002). The host range of entomopathogenic fungi is fairly wide and they can be produced in large quantities. Epizootics are made possible by the fungi that break through the insect cuticle and sporulate on dried insects (Pathak and Kumar, 2016). After the host dies from some species like *B. bassiana* and *M. anisopliae* that cause muscardine insect illness, the corpses either mummify or are covered by mycelial growth (Miranpuri and Khachatourians, 1995).

9.4.3 Viruses:

Several caterpillar pests can be effectively controlled naturally by viruses that are particular to insects. Epizootics typically decimate pest populations, especially when the quantity of insects is great. Although they must be consumed by an insect to infect them, insect viruses can also pass from one insect to another during mating or laying eggs. Baculoviruses are rod-shaped, target-specific viruses that can infect and kill a variety of significant plant pests. Their use has been constrained to small areas because of the challenges associated with their large-scale manufacture. Some caterpillar pests can be managed with nuclear polyhedrosis and granulosis viruses (Suman and Dikshit, 2010).

For the control of pest Lepidoptera like the cotton budworm and cotton bollworm, viral products for the codling moth, *Heliothis zea* and beetroot armyworm nuclear polyhedrosis virus have been registered (Arthurs and Lacey, 2004; Arthurs *et al.,* 2005). Baculoviruses can successfully combat lepidopteran pests that attack cotton, rice and crops. Although certain IPM facilities make them, they are not offered commercially in India.

9.4.4 Protozoan:

The use of protozoan infections as bio pesticide agents has not been very effective, despite the fact that they naturally infect a wide variety of pests and cause chronic and crippling effects that lower the target pest populations. For many insect species, microsporidia are the disease-causing intracellular parasites that are ubiquitous and necessary. Nosema and Vairimorpha, two genera that target lepidopteran and orthopteran insects and kill more hoppers than any other insect, have potential (Lewis, 2002). Infected midget cells slough spores into the gut lumen, where they are eliminated to the maize plant with excrement. The infection cycle is resumed for the following generation as the spores are still alive and ingested during larval feeding. When a female larva (Nosema) becomes sick and spreads the infection to the next generation, this is known as vertical transmission. The developing oocytes and ovarian tissue get infected with *N. pyrausta* as the infected larva develops into an adult. When larvae hatch, they are infected with *N. pyrausta*, which causes horizontal and vertical transmissions in natural populations of the European maize borer.

The embryo is infected within the yolk. By lowering oviposition, percentage hatch and survival of infected neonate larvae, *N. pyrausta* reduces European maize borer populations (Bidochka and Khachatourians, 1991). The microsporidian *Nosema locustae* is the only protozoan that has been approved for use as a bio pesticide.

9.5 Pest Behaviour- Modifying Chemicals:

Pest behaviour-modifying chemicals are substances or mixtures of substances released from one organism that evokes either a behavioural or physiological response between members of the same or different species. Pest behaviour-modifying chemicals are often replaced by the term semi chemicals. Semi chemicals affect the behaviour of insect pests mainly by: insect-insect or plant-insect interactions. Host-plant volatiles provide one or more of four essential resources for the insect: feeding sites, mating sites, egg-laying sites and/or refugia (Prokopy *et al.,* 1984; Witzgall *et al.,* 2010). They are considered to be valuable ecologically-friendly strategies for both monitoring and direct control of different insect pests. Recently, semiochemicals-based tactics have become an important category of integrated pest management (IPM). Pheromones and other semiochemicals are widely applied not only for controlling insect pests (Weinzierl *et al.*, 2005; Cook *et al.*, 2007; Stelinski, 2007; Heuskin *et al.,* 2009), but also for the conservation of rare and threatened insects (Larsson, 2016). There are many advantages of using semiochemicals in IPM strategies such as, their high volatility allows diffusion for long distances, application in low concentrations and rapid dissipation that reduces health and environmental risks compared with chemical pesticides. For all these reasons, utilization of semiochemicals substances provides prospective interest in IPM programs. Chemical communication that occurs between different organisms is divided into two main categories: intraspecific and interspecific, depending on how the interactions occur. Furthermore, semiochemicals are classified into several functional categories based on the type of signal they communicate and the relation between the receiver and the emitter in the communication channel (Vilela and Della Lucia, 2001).

Classification of The Semiochemicals:

9.5.1 Pheromones:

Chemicals that are species-specific signals which enable communication between life-forms of the same species i.e., intraspecific communication. Pheromones trigger a reaction in the recipient that causes changes in its behaviour (Cork 2004). In 1932, the term "ectohormone" was proposed to describe the chemicals involved in intraspecific interactions (Beth 1932), but the term was replaced by the word pheromone (Gk. phereum, to carry and horman, to excite or to stimulate) (Karlson and Butenandt 1959; Karlson and Luscher 1959). Subsequently, pheromones have been classified into eight types:

a. **Aggregation Pheromones**: attract individuals of both sexes at food sites and reproductive habitats.
b. **Alarm Pheromones:** alert members of the same species to the presence of a menace. It is considered to be the second most common pheromone produced by insects, after sex pheromones.

- **c. Oviposition-Deterrent Pheromones:** discourage females from laying eggs in the same resource of another female.
- **d. Home Recognition Pheromones:** there are common in social insect colonies. Bee queens produce a scent-mark to enable workers to recognize her colony. Queen recognition pheromones or more simply "queen pheromones" are exocrine gland products released by the queen that usually attract workers to her, eliciting care and protection.
- ***e.*** **Sex Pheromones:** mediate interaction between sexes of the same species and are mainly produced by females to attract males.
- **f. Trail Pheromones:** guide social insects to distant food sources. Trail pheromones can have both recruitment and orientation effects.
- **g. Recruitment Pheromones:** induce nest-mates to leave the nest and migrate to a work site or vice-versa. Recruitment pheromones are discharged from exocrine glands, which are anatomical structures often, specialized for synthesis and secretion (Meer and Preston, 2008).
- **h. Royal Pheromones:** recently identified from subterranean royal termites as a wax-like hydrocarbon composed of only C and H atoms called "heneicosane". This pheromone enables workers to recognize patronage (kings and queens), thereby maintaining the strain reproductive division (Funaro *et al.,* 2018).

9.5.2 Allelochemicals:

Substances which transmit chemical messages between different species are known as interspecific communication. Fundamentally, these are substances which are primarily emitted by individuals of one species and are understood by individuals of a different species. They have been divided into five categories: allomones, kairomones, synomones, antimones and apneumones (Vilela and Della Lucia 2001).

- **a. Allomones** (from Greek "allos + hormone" = excite others): released from one organism that stimulate a response in an individual of another species. The response is beneficial to the emitter, e.g. poisonous allelochemicals. They can also be seen as a deterrent emitted by insects against their predators as a defense mechanism. Granular trichomes which cover plant leaves and stems release herbivore-deterring allomones under stress conditions as a defense process. These allomones are toxic for the herbivorous insect pests, e.g. nicotine from tobacco plant.
- **b. Kairomones** (from Greek word "kairos" = opportunistic or exploitative): emitted by one organism that stimulate a response in an individual of another species. The response is beneficial to the recipient, e.g. orientation of predaceous checkered beetles (Coleoptera: Cleridae) towards the aggregation pheromone of their prey bark beetle (Coleoptera: Curculionidae: Scolytinae) (Poland and Borden 1997). Kairomones may be allomones or pheromones depending on the circumstances. For example, American bolas spiders attract their prey (male moths) by releasing attractant allomones which serve as sex pheromones emitted by female moths. Also, exudates of warm-blooded animals that pull blood-sucking insects towards their hosts serve as kairomones.
- **c. Synomones:** beneficial to both the releaser and receiver. Examples include scents used by flowers to attract pollinating insects. Moreover, herbivore- induced plant volatiles are considered to be active synomones which recruit natural enemies of insect pests

towards the affected plant (Turlings *et al.*, 1990). Also, synomones play an essential role in mate-finding communication.

d. Antimones: maladaptive for both the releaser and receiver. These substances produced or acquired by an organism that, when encountered by another individual of a different species in the natural environment, activate in the receiving individual a repellent response to the emitting and receiving individuals.

e. Apneumones (from Greek word "a-pneum" = = breathless or lifeless): emitted by a non-living source, causing a favorable behavioral or physiological reaction to a receiving organism, but harmful to other species that may be found either in or on the non-living material. Apneumones were suggested by Nordlund and Lewis (1976). Rare cases of these allelochemicals have been found later in the literature e.g. exanal and 2-methyl-2-butanol released from rabbit stools attracts sandfly females for oviposition (Dougherty *et al.,* 1995).

Factors Affect Insect Response to Semiochemicals:

a. Semiochemical Release Rate: Designing an efficient trap is mainly based on the best way of releasing attractive chemicals. The releasing rates in control strategies are considered to be critical for trapping. High release levels of semiochemicals do not actually catch more insects than lower levels. For example, the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae), responds in different ways to pheromone lure formulations in the laboratory; high release rates of pheromones were neither attractive nor repellent to beetles, whereas old traps were more suitable for use (Hussain *et al.*, 1994; Phillips 1994). Thus, optimization of releasing rates could improve the performance and efficacy of pheromone traps.

b. Trap Design: Most trapping tactics aim at improving the efficiency of a specific trap rather than information about host-plant volatiles or insect pheromones. There are many factors in trap designing that affect catching efficacy including: shape, size and height, alignment at right angles to the wind, position and timing of the trap. The most commonly used traps for catching insects in the field are sticky, water and inverted cone traps. Moreover, a combination of chemical and visual stimuli in trap design is considered to be successful when it affects responses of insects to the same lures (Singer 1986).

9.6 Role of Genetic Engineering in Pest Control:

Genetic engineering is used in agriculture to develop genetically engineered crops. These crops are intended to act as barriers against insect infestations. It helps in the development of virus and fungi-resistant crops. Agriculture benefits from the creation of genetically modified crops. This minimizes the demand for pesticides.

While research and development efforts for various *Bt* crops have been made, commercialization and cultivation permissions for these crops are subject to regulatory processes and public acceptability. To assure the environmental and human health safety of these genetically modified crops, the adoption of *Bt* technology in various crops requires rigorous safety analyses, regulatory clearances and public consent. It might be used to develop disease and drought-resistant crops.

Table 9.3: List of Biotech (BT) Crops That Have Been Developed in India

Sr. No.	Crops	
1.	*Bt* Brinjal	*Bt* brinjal is a genetically modified variety of eggplant that has been engineered to express the *Bt* toxin, specifically Cry1Ac, to provide resistance against the fruit and shoot borer (FSB) pest. Although *Bt* brinjal has been approved for commercial cultivation in Bangladesh, it has not received approval for commercial cultivation in India.
2.	*Bt* Rice	In India, genetically modified *Bt* rice has been developed to confer resistance against insect pests such as stem borers and leaf folders. Several research institutions and organizations have worked on developing *Bt* rice varieties, but commercial cultivation of *Bt* rice is yet to be approved in the country.
3.	*Bt* Tomato	Genetic engineering has also been explored to develop *Bt* tomato varieties with resistance against specific pests like fruit borers. *Bt* tomato research has been conducted in India, but commercial cultivation of *Bt* tomatoes has not been approved.
4	*Bt* Chickpea	*Bt* chickpea is a genetically modified variety of chickpea that has been engineered to express the Cry1Ac protein, providing resistance against the pod borer pest. Research and development efforts are ongoing to develop *Bt* chickpea varieties with enhanced pest resistance, but commercial cultivation has not been approved yet.
5.	*Bt* Pigeonpea	Pigeon pea (Red Gram), also known as red gram, is an important pulse crop in India. Genetic engineering techniques have been utilized to develop *Bt* pigeon pea varieties with enhanced resistance to pod borers. However, commercial cultivation of *Bt* pigeon pea is still in the research and development phase.
6.	*Bt* cotton	It was commercially introduced in India in 2002. It was developed by incorporating a gene from the soil bacterium *Bacillus thuringiensis* into cotton plants. This gene allows the cotton plants to produce the *Bt* toxin, specifically targeting the larvae of bollworm pests. *Bt* Cotton is a genetically modified cotton crop grown in India.

Currently, *Bt* cotton is the only commercially approved genetically modified *Bt* crop for cultivation in India. Therefore, there are no other *Bt* crops apart from *Bt* cotton that are widely grown in India. *Bt* cotton has been the main focus of genetic modification efforts in the country, aimed at providing resistance against certain pests such as bollworms.

Genetically modified crops specific insects targeted by BT proteins include the European corn borer, *Ostrinia nubilalis*, the pink bollworm, *Pectinophora gossypiella* and others. Due to the specificity of insecticidal actions, *Bt* crops tend to favour the growth of secondary pests that are not affected by the pesticide (Tabashnik *et al.*, 2013). Because pests are continuously exposed, many bug species have developed resistance. Due to insect resistance and secondary pest invasion, crops have been treated with neonicotinoid pesticides, which can be hazardous to bees, birds and beneficial insects.

9.7 Conclusion:

Due to food losses each year caused by pest populations, a dire need of pest modelling and extermination has surfaced on a global level (Donatelli *et al.,* 2017). Suppression of pest population is not only required for ensuring global food security but also plummeting the financial losses faced by the farmers (UNICEF, 2021). There are multiple options available for pest control in the form of chemicals, which have proven to be extremely effective in the past. However, the hazardous effects posed by chemical pesticides are also well known. To minimize the adverse impacts of chemical pesticides modern eco-friendly and sustainable techniques for controlling pest populations are being employed. Techniques such as mechanical traps, biological predators, resistant plant varieties, pheromone traps, etc. not only possess the potential of suppressing pest occurrences but also have a lesser impact on biodiversity, human health and the environment. These modern techniques have proven to be sustainable and are a better alternative to environment-degenerating chemical pesticides.

9.8 References:

1. Aneja, K. R., Khan, S. A., and Aneja, A. (2016). Biopesticides an eco-friendly pest management approach in agriculture: status and prospects. *Kavaka*, *47*, 145-154.
2. Arthurs SP, Lacey LA (2004) Field evaluation of commercial formulations of the codling moth granulosis virus: persistence of activity and success of seasonal applications against natural infestations of codling moth in Pacific Northwest apple orchards. *Biol Control* 31(3):388–397.
3. Arthurs SP, Lacey LA, Fritts RJ (2005) Optimizing use of codling moth granulosis virus: effects of application rate and spraying frequency on control of codling moth larvae in Pacific Northwest apple orchards. *J Econ Entomol* 98(5):1459–1468.
4. Barbara D, Clewes E (2003) Plant pathogenic *Verticillium* species: how many of them are there? *Mol Plant Pathol* 4:297–305
5. Beizhou S, Jie Z, Jinghui H, Hongying W, Yun K and Yuncong Y. (2011) Temporal dynamicsof the arthropod community in pear orchards intercropped with aromatic plants. *Pest Management Science*;67: 1107-1114.
6. Bidochka MJ, Khachatourians GG (1991) Microbial and protozoan pathogens of grasshoppers and locusts as potential biocontrol agents. *Biocontrol Sci Tech* 1:243–259
7. Bone N J, Thomson L J, Ridland P M, Cole P and Hoffmann A A. (2009) Cover crops in Vic-torian apple orchards: effects on production, natural enemies and pests across a sea-son. *Crop Protection*;28: 675-683.
8. Donatelli, M., Magarey, R. D., Bregaglio, S., Willocquet, L., Whish, P. M., and Savary, S. (2017). Modelling the impacts of pests and diseases on agricultural systems. *Agricultural Systems*, *155*, 213-224.
9. Dowd PF (2002) Antiinsectan compounds derived from microorganisms. In: Koul O, Dhaliwal GS (eds) Microbial biopesticides. *Taylor & Francis*, London, pp 113–116.
10. Gelernter W, Schwab GE (1993) Transgenic bacteria, viruses, algae and other microorganisms as *Bacillus thuringiensis* toxin delivery systems. In: Entwistle PF, Cory JS, Bailey MJ, Higgs S (eds) *Bacillus thuringiensis*, an environmental biopesticide: theory and practice. Wiley, *Chichester*, pp 89–124.

11. Hegde R, Lingappa S. (1996) Effect of inter cropping on incidence and damage by *Helicoverpa armigera* in pigeonpea. *Karnataka Journal of Agricultural Sciences* 9: 616-621.
12. Hormchan P, Wongpiyasatid A, Prajimpun W (2009) Influence of trap crop on yield and cotton leafhopper population and its oviposition preference on leaves of different cotton varieties/ lines. *Kasetsart J* (Nat Sci) 43:662–668.
13. Khachatourians GG (2009) Insecticides, microbials. *Appl Microbiol*:95–109.
14. Letourneau D K, Armbrecht I, Rivera B S, Lerma J M, Carmona E J, Daza M C, Escobar S, Gallindo V, Gutierrez C, Lopez S D, Mejia J L, Rangel A M A, Rangel J H, Rivera L, Saavedra C A, Torres A M and Trujillo A R. (2011) Does plant diversity benefit agroecosystems? A synthetic review. *Ecological Applications*; 21: 9-21.
15. Lewis LC (2002) Protozoan control of pests. In: Pimental D (ed) Encyclopedia of pest management. *Taylor & Francis*, New York, pp 673–676.
16. Lin B B. (2011) Resilience in agriculture through crop diversification: adaptative management for environmental change. *BioScience*;61: 183-193.
17. Mazid S, Kalita JC, Rajkhowa RC (2011) A review on the use of biopesticides in insect pest management. Int J Sci Adv Technol 1:169–178.
18. Miranpuri GS, Khachatourians GG (1995) Entomopathogenicity of *Beauveria bassiana* toward flea beetles, *Phyllotreta cruciferae* Goeze (Col., Chrysomelidae). *J Appl Ento* 119:167–170.
19. Pathak DV, Kumar M (2016) Microbial inoculants as biofertilizers and biopesticides. In: Singh DP et al (eds) Microbial inoculants in sustainable agricultural productivity. *Springer*, New Delhi, pp 197–209.
20. Pineda S, Alatorre R, Schneider M, Martinez A (2007) Pathogenicity of two entomopathogenic fungi on *Trialeurodes vaporariorum* and field evaluation of a *Paecilomyces fumosoroseu* isolate. *Southwestern Ento* 32:43–52.
21. Ratnadass A, Fernandes P, Avelino J, Habib R (2012) Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: A review. *Agro Sustain Dev* 32:273–303.
22. Sharma HC. (1985) Strategies for pest control in sorghum in India. *Tropical Pest Management* 31: 167-185.
23. Suman G, Dikshit AK (2010) Biopesticides: an ecofriendly approach for pest control. *J Biopest* 3(1 S):186–188.
24. Tillman PG, Khrimian A, Cottrell TE, Lou X, Mizell RF, Johnson CJ (2015) Trap cropping systems and a physical barrier for suppression of stink bugs (Hemiptera: Pentatomidae) in cotton. *J Econ Entomol* 108:2324–2334.
25. Tooker J F and Frank S D. (2012) Genotypically diverse cultivar mixtures for insect pest management and increased crop yields. *Journal of Applied Ecology*;49: 974-985.
26. UNICEF. (2021). The state of food security and nutrition in the world 2021.
27. Zhou Z, Chen Z, Xu Z (2010) Potential of trap crops for integrated management of the tropical armyworm, Spodoptera litura in tobacco. *J Insect Sci* 10:117.