EMERGING TRENDS IN
PLANT PROTECTION SCIENCES

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Abstract:

Climate change has emerged as a pivotal force reshaping ecosystem and impacting various interactions, notably those involving insect pests. As the temperature rise, insects respond by altering their developmental rates, leading to shifts in phenology and geographic ranges. Changes in precipitation patterns influence pest distribution and abundance, driving novel interactions with host plants and predators. Climate change-induced shifts in temperature and precipitation patterns are amplifying plant stress, creating favourable conditions for increased pest populations. Additionally, evolving weather patterns impact insect population dynamics, potentially exacerbating pest outbreaks. The behavioural shifts of insect pests, brought about by climate change, can disrupt pest management strategies.

However, these changes also prompt opportunities for innovative mitigation approaches. Natural selection pressures arising from changing environments drive pest adaptation and evolution, impacting pest-induced alterations in speciation and genetic makeup can lead to the emergence of new pest biotypes. Mitigation and management strategies in the face of changing pest dynamics require a climate-smart approach. By embracing climate-smart agricultural practices and innovative pest control methods, stakeholders can navigate the challenges posed by changing pest dynamics in rapidly warming world.

Keywords:

Climate change, Insect, Pest, Adaptation, Weather, Temperature, Evolution

1.1 Introduction:

Climate change stands as a major worldwide dilemma in our era, carrying extensive repercussions for both ecosystems and human communities. The rapid rise in greenhouse gas emissions, primarily driven by human activities, has led to unprecedented changes in temperature, precipitation patterns, and overall climatic conditions worldwide. These changes occurring within the earth's climate system have significant effects on a range of ecological mechanisms, including the relationships between insects and their surroundings.

The climate plays a vital role in shaping the features and arrangements of both controlled and natural systems, encompassing aspects such as water resources and hydrology, cryology, marine and freshwater ecosystems, terrestrial ecosystems, forestry, and agriculture (Grimm et al., 2013; Peñuelas et al., 2018; Poff et al., 2002).

Numerous studies have highlighted the critical role of climate in shaping the distribution and behaviour of insect pests. Climate variables, such as temperature, humidity, and rainfall, directly influence the life cycle, reproductive rate, and geographic ranges of insects (T. Jaworski & Hilszczański, 2013). Moreover, climate-related changes in host plant phenology and quality can significantly affect the abundance, distribution and survival of insect pests (Peace, 2020). Consequently, alterations in climate conditions can disrupt the delicate balance between insects, their natural enemies, and the plants they rely upon.

As the global climate continues to increase, these complex interactions are likely to be further disrupted, leading to substantial consequences for pest management strategies and agricultural productivity. Rising temperatures can accelerate insect development rates, resulting in shorter generation times and increased pest population (Harvey & Dong, 2023). Also, changing precipitation patterns may favour the proliferation of certain pest species by providing favourable conditions for their reproduction and survival.

The impact of climate change on insect pests extends beyond agriculture and has implications for ecosystem dynamics also. Insects plays a crucial role as pollinators, decomposers, and prey for other organisms. Changes in the abundance, distribution and phenology of insect pests can disrupt various ecological interactions and have cascading effects on other species and ecosystem balance (Buckley, 2022). In this chapter we have discussed the impact of climate change on insect pests. Specifically, we delve into the effects of rising temperatures, shifting precipitation patterns, and evolving weather phenomena on the behaviour, adaptation, and evolution of these pests. Moreover, we scrutinize the intricate interplay between changing climatic conditions and insect pest’s genetic makeup, speciation, and overall population dynamics.

1.2 Temperature Changes and Insect Pest Distribution:

Human activities since the industrial revolution have led to the emission of carbon dioxide and other greenhouse gases into the atmosphere, resulting in alterations to the earth’s climate. The temperature is being affected more and more by the use of fossil fuels, cutting down of forests, and farming of livestock. Insect distribution can be affected significantly by temperature change. The distribution of insect pests can be affected in several ways by temperature change.

With rising temperatures, there’s a potential for insect pests to enlarge their geographical distribution and inhabit regions they couldn’t previously thrive in (Battisti & Larsson, 2023). Increasing temperature can enable pests to colonize new areas, causing damage to previously unaffected crops or ecosystems (Pureswaran et al., 2018). The temperature of insects is controlled by the external environment, which means they are ectothermic organisms (Abram et al., 2017). The metabolic rate of these animals can be accelerated by higher temperatures consequently, the population in affected areas can increase and pest pressure will increase (Skendžić, Zovko, Živković, et al., 2021). Insects life cycles can be disrupted and their seasonal patterns altered by changes in temperature (Harvey, 2020). Warmer winter may allow increased overwintering survival and earlier emergence in the spring. This can lead to larger growing season for pests and increased damage to crop or vegetation (Bale et al., 2002). Insects typically have lost plants or specific ecosystem they rely on for survival. With temperature change, the availability and suitability of these host plants may shift. This can lead to change in insect pest distribution as they search for new resources or adapt to different plant species (Skendžić, Zovko, Živković, et al., 2021).

Temperature change not only affects insects' pests but also their natural enemies, such as predators and parasitoids (Jactel et al., 2019). Warmer temperature may favour the development and reproduction of certain insect pests, while negatively impacting the survival or effectiveness of their natural enemies. This can disrupt the natural control of pest populations and potentially lead to increased pest damage (Harvey et al., 2020). Overall, temperature change can have complex and varies effect on insect pest distribution. It is important to closely monitor these changes and understand their implications for managing insect pests in agricultural and natural ecosystem.

1.2.1 Changes in Precipitation Patterns and Insect Pest Abundance:

The majority of scientists in the world concur that global warming has impacted rainfall patterns. Changes are being made in the quantity, distribution, and timing of precipitation events, such as rain, snow, and sleet. The number of precipitation events tends to be less frequent, but their intensity tends to be higher. Changes in precipitation patterns can also significantly impact insect pest abundance. Precipitation patterns can have an impact on the exact conditions that insects need to develop and reproduce. Precipitation changes, such as more frequent or strong rainfall events or protracted droughts, might change the number of pest breeding sites that are available. An increase in mosquito numbers might result from excessive rain creating standing water that makes it easier for mosquitoes to spawn (Filho et al., 2019). Insects depend on host plants for survival and sustenance, and precipitation patterns can have an impact on both their number and health. Both the development and quality of host plants can be impacted by changes in rainfall since these changes can modify the amount of moisture and nutrients in the soil. This may alter how many and how suitable host plants are for pests, thereby affecting pest populations.

Changes in precipitation patterns can also affect the population and behavior of natural enemies such as parasitoids and predators (Eigenbrode et al., 2015). This disruption in natural enemy population can result in increased pest abundance and damage. Insect pest can rely on wind or water for dispersal to new areas. Shifts in precipitations pattern can affect these dispersal mechanisms and potentially influence the spread and distribution of pests. For example: heavy rainfall can assist windborne spread of certain pests, enable them to colonize new locations (Skendžić, Zovko, Pajač Živković, et al., 2021). Insects have evolved to respond to specific environment cues, including precipitation pattern. Alteration in timing and amount of rainfall can disrupt insect behavior and life cycles. For instance increased or prolonges period of rainfall can lead to delay in emergence, mating or oviposition, affecting the population dynamics and abundance of insect pests (Nayak et al., 2020).

1.2.2 Extreme Weather Events and Their Influence on Insect Pests:

Extreme weather events such as hurricanes, floods, droughts, heat waves and severe storm can have significant impact on insect pests. These events can either increase or decrease the population size and distribution, depending on the specific conditions and adaptability of pest species (Skendžić, Zovko, Živković, et al., 2021). Extreme weather events can disrupt the life cycle of insect pest by affecting their breeding, development and survival. For example: flooding can wash away insect's eggs or larvae, reducing their population (Shrestha, 2019). Similarly heat waves can accelerate the growth and reproduction of pests, leading to population blooms. Extreme weather events can alter the geographic distribution of insect's pests. Warmer temperature and change in precipitation pattern can expand the range of pests, causing damage to crops, forests and ecosystems. Certain extreme weather events such as drought can weaken the natural defense of plants against pests. Plants stressed by drought conditions become more vulnerable to insect infestation, as they may reduce ability to tolerate pest feeding. This can lead to increased pest outbreak and damage to crops (War et al., 2016)

Mosquitoes and ticks, and other insects, serves as vectors for a range of illnesses, including malaria, dengue fever, and lyme disease (Baylis, 2017). Extreme weather events that create favorable conditions for these vectors, like high temperature and heavy rainfall, can lead to increasing the risk of malaria and other mosquito borne disease(Anand et al., 2014). Extreme weather events can also affect the effectiveness of pest control measure. Heavy rainfall can wash away insecticides, reducing their efficacy while strong winds can disperse beneficial insects that help control pest populations. Moreover, extreme weather events may limit access to affected areas, hampering pest management efforts and increasing the risk of pest outbreak.

1.2.3 Changes in Insect Pest Behaviour and Activity Patterns:

Climate change can have significant impact on insect pest behaviour and activity patterns. Climate change can alter the suitable habitat for insects. As temperature increase, pest may expand their geographic range and invade new areas. For example there are certain pests that were previously limited to warm tropical region may now be able to survive and thrive in more temperate regions due to milder winters (Keutgen, 2023).

Warmer temperature and longer growing season can result in extended breeding season for insects. This allows them to produce more generations per year, leading to larger populations and increased damage to crops, causing economic losses. Climate change can disrupt the timing of life cycle events. Such as emergence, migration and hibernation, for many insects. Warmer temperature can cause insects to emerge earlier in the spring, leading to mismatch with the availability of their food source or pollinators. This can have negative consequences for both the insects and the plant they interact with (Id & Holzschuh, 2019).

Insects may modify their behavior and activity pattern in response to climate change. For example: Some pests may exhibit increased feeding rates or adapt to warmer temperature by changing their daily activity schedules. These changes can have implications for crop damage, disease transmission, and ecosystem functioning. Climate change can create more favorable conditions for insect pest, allowing their population to grow their population rapidly and cause outbreaks. Higher temperatures and increased humidity can accelerate their growth and reproduction rates. Additionally, warmer winter may not provide adequate cold period to suppress pest population, leading to increased survival and expanding range. The relationships between insect pests and the plants they feed on can be influenced by climate change (Jactel et al., 2019). Pests may respond differently to change in temperature, precipitation and atmospheric carbon dioxide level, which can impact their feeding behavior, reproduction, and host plants selections. Such changes can have cascading effects on plant health, crop yields, and ecosystem dynamics.

1.2.4 Adaptation and Evolution of Insect Pests in Response to Climate Change:

Insect pests have the ability to adapt and evolve in response to climate change. Insect pest can exhibit phenotypic plasticity, which refer to their ability to adjust their characteristics and behavior in response to environmental cues. Change in temperature, precipitation and other climate factors can trigger plastic response in insect pests, such as altered feeding behavior, reproduction rates and development time.This phenotypic plasticity allows pests to exploit new resources and survive in changing conditions. Overtime insect pest can undergo genetic adaptation to cope with changing environments (Armin, 2010). Individual with genetic variations that confer better survival and reproduction success in the new climate conditions are more likely to pass on their genes to future generations. This can lead to the development of populations with traits that are better suited to the changing climate. Insect pest have short generation times and high reproductive rates, which can facilitate rapid evolution. This allows them to respond quickly to selective pressure imposed by climate change.

Pest may evolve to have different environmental threshold in response to changing temperature pattern, enabling them to synchronized their life cycles with the availability of host plants or favorable conditions. Climate change can create suitable environment for insect pest in regions that were previously unfavorable. Pests may rapidly expand their ranges and colonize new areas where they are not previously present. This range expansion can involve the evolution of traits that enable pests to survive and reproduce in the noble environments, such as adaptation to different temperature regimes or host plant species. Insect pest can also evolve in response to the response of their host plants to climate change. A pest's selective pressure can be affected by changes in plant phenology. Due to climate change, pests may evolve mechanisms for overcoming plant defenses or exploiting novel host plant species. Although insect pests are capable of adapting and evolving, they can be influenced by a number of other factors besides climate change, such as available habitat, interactions with other organisms, and the speed and magnitude of climate change. Furthermore, this evolutionary response can have both positive and negative implications for agriculture, ecosystem, and human health, and must be carefully managed and monitored.

A. Speciation and Genetic Alterations:

Insect pests can also undergo speciation, which is the formation of new species, due the impact of climate change. Speciation can also occur when population of insect pest become isolated from one another and diverge genetically, resulting in the development of distinct species. Changing in climate and habitat availability can cause insect pest to come into contact with other related species that may not have previously encountered. Hybridization, the interbreeding between different species, can occur as a result of these encounters. in some areas, hybrid individual may exhibit higher fitness in the new environmental conditions, leading to the establishment of hybrid population that can evolve into new species.

Climate change can lead to genetic alterations in insect pest through various mechanisms. Climate change can impose new selective pressure on insect pests favoring individuals with specific genetic mutation that enable them to cope with changing conditions. Climate change can alter the distribution and migration pattern of insect pest. As populations move and encounter new environments gene flow can occur between different populations.

These genetic variations may contribute to adaptations and allow pest to persist and thrive in the face of changing climatic conditions. Insects have the ability dynamically adjust their genetic response to environmental changes through epigenetic modifications and change in gene expression (Villagra & Frías-Lasserre, 2020). This flexibility in gene regulations allow insect pest to rapidly respond to climate change and adjust their phenotypes, such as altering their environment rate to tolerance to extreme temperatures, without necessary undergoing genetic mutations.Genetic introgression: hybridization events can occur, resulting in genetic introgression where gene from one species is incorporated into the gene pool of another species. These introgressed genes may bring new adaptive trait or enhance genetic diversity, potentially influence the evolutionary trajectory of pest populations.

B. Plant Stress and Economic Loss:

Agriculture is essential to supplying the world's expanding food demand, but it faces ongoing biotic and abiotic stress factors. Among these, drought stress stands out as a serious risk to agricultural productivity and causes financial losses in the agricultural sector (Ahluwalia et al., 2021). Farmers' and forest managers' financial losses are exacerbated by the combined effect of biotic and abiotic stress factors, which offers additional difficulties for forestry and agriculture (Fahad et al., 2017; Teshome et al., 2020). The production of crops is consistently impacted by several factors, such as limited land sizes, inadequate mechanization, and the existence of diverse abiotic and biotic stresses (Dev, 2012). Apart from the challenges discussed earlier, different crops encounter diverse types of biotic and abiotic pressures. Biotic stress is any stress brought on by living things like bacteria, fungus, viruses, insects, and other creatures of the night. Even after being exposed multiple times, the plant does not develop a resilient defence against biotic stress. This is why pre- and post-harvest losses are primarily caused by biotic stress (Lal et al., 2023). Abiotic stress refers to problems like oxidative stress, metal toxicity, high soil salinity, and drought. These stresses possess the capability to cause lasting damage to a plant, leading to hindered growth, disrupted metabolic processes, reduced productivity, and alterations in genetic patterns that lead to mutations in progeny (Zaidi et al., 2014). One such abiotic stress that significantly lowers agricultural yield each year is drought stress. Drought conditions are brought on by a lack of water due to a decrease in rainfall and an increase in the frequency of dry spells. Often, in addition to its negative consequences, drought is accompanied with salt, heat, and disease invasion (Hossain et al., 2016). Plants undergo various physiological and structural alterations due to stress, encompassing reduced rates of transpiration and photosynthesis, adaptations in osmotic balance, inhibited growth of roots and shoots, elevated production of reactive oxygen species, modifications in stress-related signalling pathways, and accelerated senescence (Heim, 2002).

C. Crop Losses and Economic Impacts:

Crop losses have a substantial financial impact on agriculture and food security. Reductions in yield are caused by a variety of events, such as weed infestations and floods, which costs farmers and the agricultural industry money. Natural disasters like floods pose a serious threat to world agriculture. According to a study to evaluate the effects of floods on crop production, floods significantly reduce the yield of important crops. According to the study, global average yield losses over return periods longer than 10 years were predicted to be around 4% for soy, 3% for rice, 2% for wheat, and 1% for maize. Between 1982 and 2016, these losses led to a total output loss of 5.5 billion dollars in the United States. Following droughts as the second-worst agricultural calamity, floods cost the developing countries $21 billion in lost crops and livestock between 2008 and 2018. To increase the agricultural system's flood resilience and guarantee food security, effective management of flood hazards is essential (Kim et al., 2023).

Weeds are infamous for lowering yields and having serious economic effects on agriculture. An Indian study calculated the production and monetary losses brought on by weeds in important field crops. For crops like soybean (50–76%) and groundnut (45-71%), potential yield losses were shown to be significant. Rice incurred the highest real economic damages, amounting to $4420 million, trailed by wheat at $3376 million, and soybean $1559 million. The actual economic damage caused by weeds in India's ten main crops was calculated to be at USD 11 billion. Achieving sustainable agricultural goals requires lowering exposure and vulnerability to weeds, which is a crucial component of crop productivity (Gharde et al., 2018).

1.2.5 Economic Consequences of Climate- Induced Insect Pest Outbreaks:

The interplay between plants, pathogens, pests, and the environment holds significant importance in the occurrence of plant diseases and pest infestations. In addition, bark beetle outbreaks frequently accompany other biotic and abiotic forest disturbances. As a result of worldwide climate change and related natural disruptions, there has been a noticeable rise in the negative impacts and losses caused by insect infestations in recent times (Ivantsova et al., 2019).

Pathogens, insect pests, temperature extremes, and nutrient deficits are just a few of the biotic and abiotic stress factors that together cause significant output losses in both agriculture and forestry (Ayres & Lombardero, 2000; Weed et al., 2013). Studies have indicated that abiotic stresses including temperature extremes, drought, and nutrient deficits can cause production losses ranging from 51% to 82% whereas biotic stresses like pests, diseases, and weeds can result in yield losses ranging from 17.2% to 30.0% in important food crops. Similar to this, large biotic and abiotic pressures in forestry have had an impact on important forest regions, leading to a drop in the world's forest area (Teshome et al., 2020). More than half of the country's area is covered by forests, and disturbances like wildfires and pest outbreaks pose a serious threat to their ecosystems from an economic standpoint, including a loss in the commodities and services they supply. The extent of forest land impacted by pests that consume conifer trees has been rapidly increasing. It went from 353.3 thousand hectares in 2005 to 1117.7 thousand hectares in 2017, even though there was a 14-year period of reduction in the overall forest area affected by pests. The total amount of forest impacted by wildfires is also on the rise; from 2010 to 2017, it increased by more than 67%. Many countries in the boreal zone have seen similar developments.

It is obvious that outbreaks of insect pests could end up being the main factor restricting the forest economy. Despite a recent decline in the annual rate of forest loss (d'Annunzio et al., 2015; Keenan et al., 2015) and an increase in planted forest area (Payn et al., 2015), the global forest area is predicted to continue decreasing. According to Keenan et al. (2015), the worldwide forest area declined from 4.12 billion hectares to 3.99 billion ha between 1990 and 2015, whereas the area of planted forests expanded from 167.5 million ha to 277.9 million ha over the same time period. According to d'Annunzio et al. (2015), the world's forest acreage will continue to shrink during the next ten years, but at a slower rate. However, Song et al. (2018) discovered that between 1982 and 2016, the overall area of global tree covers increased.

Rising temperatures have also been linked to higher infestations of Picea abies by *Ips typographus* in Europe (Marini et al., 2017; Mezei et al., 2017) as well as increased spruce budworm (*Choristoneura spp.*) outbreaks in North America (De Grandpré et al., 2019). This is consistent with how rising temperatures affect insects' ability to reproduce and survive (Pureswaran et al., 2018). If warming does not coincide with key stages of an insect's life cycle, such as overwintering, it may have no impact on pest outbreaks. In this regard, Gazol et al. (2019) shown that only warmer winters had an impact on the outbreak of the pine processionary moth, *Thaumetopoea pityocampa*. These data suggest that, although rising temperatures may lead to an increase in insect outbreaks, this may not always be the case.

A. Ecological Consequences and Biodiversity Loss:

Ecological disruptions of forests brought on by insect pests pose a severe threat to both the wellbeing of humans and other natural ecosystems. Deforestation, shifting cultivation, and wildfire continue to be the key factors contributing to the decline in the worldwide forest area (Curtis et al., 2018). Although biotic and abiotic pressures appear to have a minimal direct impact on such forest losses (Curtis et al., 2018), their indirect effects should not be understated. As an example, instances of forest fires often coincide with tree mortality triggered by infestations of insect pests, periods of extreme heat, and prolonged droughts. These factors lead to substantial losses in the tree population (Brando et al., 2014; Klein et al., 2019; Talucci & Krawchuk, 2019; Xie et al., 2020). The incidence of biotic and abiotic pressures can vary regionally and across time, which emphasizes the significance of these elements. For instance, 32% of tree mortality in the Western United States was attributed to pests, compared to 18% loss from fire (Berner et al., 2017). Another research revealed that the primary factors behind disruptions in northern hemisphere forests are biological disturbances, such as diseases and insect pests (Kautz et al., 2017).

Diminished product quality and the influence of combined biotic and abiotic stresses on the survival and growth of forest trees can both lead to a decline in the supply of essential services and subsequently lead to a decrease in direct earnings (Aukema et al., 2011). It has been suggested—although it is debatable—that climate change promotes tree growth and subsequently forest production (Reyer et al., 2017; Ruiz-Pérez & Vico, 2020; Torzhkov et al., 2019). Even if there might be an increase, the effect of harsh weather on the spread of pathogens and pests would result in significant losses and could even cancel out any improvement in output (Reyer et al., 2017)**.** The interference with the cultural and regulatory roles of trees, coupled with a rice in tree mortality and damage to their upper branches and foliage due to a combination of living organism related and environmental stresses, could negatively impact the overall human welfare (Reid, 2005). According to Donovan et al. (2013) and Jones (2019), both rising temperatures brought on by the loss of canopy shade and increased forest densities have been linked to increased respiratory disease-related human health issues (Donovan et al., 2013; Jones, 2019). Massive tree mortality may also have an effect on the micro- and macrofaunal variety as well as the floral diversity of the forest ecosystem. For instance, the emerald ash borer's (*Agrilus planipennis*) huge ash (*Fraxinus spp*.) mortality induced a canopy gap and a buildup of woody debris, which have an impact on the activity and diversity of forest invertebrates. Massive tree mortality may also result in a drop in lichen populations, which could result in local extinction (Jönsson & Thor, 2012).

Quantifying the monetary value of the diverse damage caused by living organisms and environmental factors is a complex task. Nevertheless, efforts have been undertaken to estimate the financial impacts from different perspectives. The financial loss brought on by tree death and slower growth serves as a clear indication of these effects. In spite of the unfavourable ecological effects brought on by the related increase in harvest frequency, dead trees, especially mature ones, might still have economic worth through "salvage logging". Projected economic losses resulting from anticipated tree mortality were used to illustrate the potential harm caused by both biotic and abiotic stresses (Ochuodho et al., 2012; Soliman et al., 2012), comparisons of the cost of protection to the possible loss, and revenue loss due to downgraded products (Costanza et al., 2019). Estimates of governmental, household, and property value losses linked to tree mortality have also been made (Reid, 2005). A more comprehensive evaluation took into account economic damages stemming from production, conservation efforts, tourism, and carbon stoage (Notaro et al., 2009). Future research should take these elements into account while conducting their assessments, as losses like tree mortality are mostly caused by the interaction of biotic and abiotic pressures. Furthermore, as economic analysis is crucial for decision-makers and forest managers, it is vital to methodically analyses the data, which is typically available in technical reports.

1.2.6 Impact of Insect Pest on Native Flora and Fauna:

Insects play a vital role in ecosystems as pollinators, decomposers, and prey for other species. However, some insect pests can harm local plants and animals, upsetting the ecological balance and causing serious problems for biodiversity and ecosystem health. This article examines how insect pests affect native plants and animals, including current findings and authoritative statements about how bug populations will be exacerbated by climate change.

The increase in global surface temperature has various impacts on insects, leading to changes in their physical attributes, actions, life-cycle timing, geographical range, and relationships with other species. Additionally, the difficulties faced by insects are made worse by extreme occurrences like heat and cold spells, fires, droughts, and floods, which are occurring more frequently as a result of climate change (Harvey et al., 2023). Because it can have a domino impact on ecosystem services like pollination, nitrogen cycling, and pest control, the loss of insect populations is a serious concern.

Habitat or vegetation management is a part of conservation biological control, a practice meant to increase the effectiveness of natural enemies in eradicating pests. Recent years have seen an increase in interest in the utilization of native plants for biological conservation. These plants give natural enemies, including predatory insects, vital floral resources that support their population and increase their ability to reduce pest populations.

Although this strategy has promise, there are still questions regarding the mechanics underpinning it, how it affects pest populations, and how much it will cost to use it. The transferability and widespread implementation of this conservation technique in different agricultural systems and regions will be made possible by including these features into study (Zaviezo & Muñoz, 2023).

Developing efficient pest management solutions requires an understanding of the link between insect pest density and survival. According to studies, the survival rate of some mosquito species, such as Aedes larvae, declines when larval population rises. Controlling larval density may not necessarily result in fewer adults because the survival-density connection varies greatly in the wild. According to field research, there are rare circumstances when larval management may even lead to an increase in adult output. This variation demonstrates the difficulty in controlling insect pest populations and the requirement for site-specific strategies(Li et al., 2023).

Insect pests' influence on local flora and fauna as well as the fall in insect populations call for immediate attention. Implementing sustainable farming practices, cutting greenhouse gas emissions, and protecting natural habitats are essential steps in improving ecological resilience and minimizing the negative consequences of climate change on insect populations. Additionally, more research and creative approaches, including conservation biological control using native plants, show promise in conserving the fragile ecosystem balance and the priceless services that insects give in the natural world.

A. Mitigation and Management Strategies:

Mitigation and management strategies for integrated pest management approaches involve a combination of techniques aimed at effectively controlling pest while minimizing potential harm to humans, the environment, and non-target organisms. Emphasizing preventive measures such as proper sanitation, crop rotation, and regular monitoring of pest populations can help reduce the need of chemical interventions. Encouraging the natural enemies, such as beneficial insects or microbial agents, to suppress pest populations is an important tactic in IPM. This can be done through conservation, augmentations or introduction of these natural enemies (Saeed Ben Youssef, 2023).

Modifying cultural practices, such as planting resistant crop varieties, selecting appropriate planting dates, or implementing proper irrigation and fertilization techniques, can help reduce pest susceptibility and increase overall crop health. Implementing physical barriers, like screen, nets or fences, can prevent pest from accessing crops or structure, providing an effective non-chemical mean of pest control.

If necessary, the use of chemical pesticides is integrated into IPM. Regular monitoring and scouting for pests allow early detection and intervention only, when necessary, based on predetermined actions thresholds. Educating farmers, pest control professionals, and the wider community about the principles and benefits of IPM approach is crucial for successful implementation.

B. Climate-Smart Agriculture and Pest Management:

Climate smart agriculture aims to address the challenges posed by climate change while ensuring sustainable food production. Pest management is the critical component of CSA, as changing climate condition can have a significant impact on pest dynamics and the spread of invasive species. Implementing IPM principles with CSA can help farmer effectively manage pest while minimizing environmental impact. Natural enemies, crop rotation, and cultural practices can suppress pests and reduce the need for chemical pesticides.

Climate change can lead to shift in pest population and their distribution. Selecting and breeding crop varieties that are more resilent to pests and climate change stressors can help minimize the pest damage. Early warning system: developing and implementing early warning system can help farmers anticipate and respond to emerging pest threats.

These systems can use climate data, pest population monitoring, and predictive modeling to alert farmer to potential outbreaks and guide timely interventions. Ecosystem based approach: adopting ecosystem-based approaches, such as promoting biodiversity and conserving natural habitats, can provide natural pest control services. Healthy and diverse ecosystem support beneficial organisms that help suppress pests.

Crop diversification integrating diverse crop into farming system can help reduce pest pressure. By planting a variety of crops, pests are less likely to build up large populations that can cause significant damage (C. C. Jaworski et al., 2023). Improved irrigation and water management proper irrigation and water management practices can minimize conditions that promote pest development, such as waterlogged or overly or overly dry soils. This can help reduce the incidence of water related pests and diseases.

Capacity building and knowledge sharing providing farmers with training, information’s, and resources on climate-smart pest’s management practices is crucial. Capacity building programs can help farmers understand the impact of pest dynamics and learn about effective pest management techniques. By integrating pest management strategies into climate change agriculture practices, farmers can reduce pest pressure, minimize reliance on chemical pesticides, and enhance the resilience and productivity of their farming systems in the face of climate change (Heeb et al., 2019).

1.3 Conclusion:

The intricate interplay between rising temperatures, altered precipitation patterns, and shifting weather dynamics has not only influenced the behaviour and distribution of insect pests but has also triggered cascading effects on plant stress, adaptation, and even evolution. The evidence presented underscores the urgency of recognizing climate change as a significant driver of insect pest dynamics. The alterations in insect behaviour, such as shifts in migration patterns, feeding habits, and reproductive cycles, have far-reaching consequences for agricultural ecosystems, biodiversity, and human livelihoods. The increased frequency of extreme weather events further exacerbates these impacts, leading to unpredictable pest outbreaks and economic losses in agricultural sectors. Effective pest management strategies must account for evolving behaviour and distribution of insect pests, while also considering the resilience of plant species. Collaborative efforts between researchers, policymakers, and agricultural stakeholders are essential to develop adaptive strategies that mitigate the negative impacts of climate change on insect pests and ensure global food security. By fostering a deeper comprehension of these dynamics, we can pave the way for innovative solutions that safeguard our agricultural systems, preserve biodiversity, and ultimately contribute to a more sustainable and resilient future.

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2. Morphological Changes in Plants in Response to Insect Pests

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Abstract:

Insect pest pose a significant threat to global agriculture, causing substantial yield losses and economic damages. To combat these pests, plants have evolved a multitude of defense mechanisms, including various morphological changes. These changes encompass a wide range of adaptations, including alterations in leaf structure, the development of specialized structures, and changes in root morphology. These morphological adjustments are often accompanied by changes in plant physiology and biochemistry, collectively constituting an integrated defense strategy. Morphological changes occur in plants both above and below-ground level. Climate change can alter temperature, humidity, precipitation patterns, and distribution of pests, which in turn leads to various morphological changes in plants in relation to leaf thickness and texture, trichome density, altered flowering and seed production etc. Climate-driven adaptations can influence the interactions between plants and herbivores, potentially leading to shifts in the composition of plant and pest communities over time.

Keywords:

Morphology, Trichome, Root system, Climate change

2.1 Introduction:

Plants as sessile organisms have evolved intricate defense mechanisms to counteract the myriads of challenges presented by their dynamic environment. Among these challenges insect pests pose a significant threat to plant survival, exerting selective pressure that has driven the development of a diverse array of adaptive strategies (Skendžić et al., 2021). Insect pests ranging herbivorous to parasite represent one of the most potent selective pressures on plants. As herbivorous consume plant tissues for sustenance impose a constant threat to fitness of plants (Miller & Raman, 2018). The relationship between plants and insects represents a complex web of interactions, ranging from mutualistic to antagonistic, each employ an array of strategies to ensure its survival and reproductive success (Nepi et al., 2018). This dynamic interplay has driven the co-evolution of plants and insects, leading to an evolutionary arm race characterized by remarkable and counter adaptations. As plant develops defense mechanism to deter herbivory insects evolve counter strategies to overcome these barriers (War et al., 2012).

This escalation of adaptation is a driving force behind the remarkable changes observed in plants in response to insect pests. Morphological changes in plants as a response to insect pests are multifaceted and can encompass alterations at various organizational levels, from cellular structure to entire plant organs. These changes can be rapid, occurring within hours of herbivore attack, or may develop gradually as a part of a longer-term defense strategies. They often entail shift in plant growth patterns, resource allocations, and structural modifications, all aimed at deterring herbivores, mitigating damage, and ultimately enhancing plant survival and reproduction. These adaptations can be categorized into those occurring above the ground, below the ground, and even at the structural level. Structural modifications such as development of thornes, prickles and spines further discourage herviorous from feeding on plants. These hardened structures often arise from modified leaves or stems; create physical barriers that prevent formidable challenge to would be herbivore. Furthermore, plants have developed a sophisticated array of chemical defense that is deeply interwined with their morphological adaptations. This defense manifest as secondary metabolites such as alkaloids, terpenoids, and phenolic compounds, effectively deployed chemical weaponry that repel herbivores and or attack their natural predators thus creating a delicate ecological balance. Understanding the mechanisms that underlie these morphological changes require a comprehensive exploration of intricate signaling pathways, hormonal network and genetic factor that orchestrate the plants response. In this chapter we have discussed the diverse morphological adaptations that plant employ in response to pest pressure and also the role of abiotic factors in shaping plant morphology.

2.1.1 Morphological Adaptation of Plants above Ground:

Plants adapt to environmental stress by altering their metabolism, flowering, growth, and reproduction; and by migrating toward areas with more favorable climatic conditions. Climate change has significant effects on the morphological adaptation of plants above ground level. Here are some impacts:

A. **Increased leaf area**: Leaf morphological traits vary systematically along climatic gradients. Rising temperature and elevated carbon dioxide levels can stimulate photosynthesis in plants, leading to increased leaf area. This allows plants to capture and utilize more sunlight for energy production (Gamage et al., 2018). There are two mechanisms identified by which this happens: wall extensibility, which progressively alters the leaf over time and permanently enlarges it, or osmotic regulation, which has a transient effect that causes leaves to grow in size. The different leaf diameters of plants growing in the same habitat are anticipated to have unique thermal regulation capacities that affect leaf water loss and heat loss.
B. **Altered leaf shape and size**: The use of leaf morphological attributes for species identification dates back to long time and is frequently recognized as diagnostic of species. These traits include leaf colour, shape, orientation, and degree of marginal dissection. changes in temperature, moisture availability, and CO2 level can influence leaf morphology. For example, in response to higher temperature, plants may develop larger, thinner, leaves to enhance the heat dissipation through transpiration (Vicente-serrano et al., 2022). Different mechanisms have developed to control plastic, heterophyllous responses to changes in temperature and light quality as well as heteroblastic changes in leaf shape in response to photosynthesis.

C. **Shift in flowering and fruiting patterns:** Climate change can disrupt flowering and fruiting cycle of plants. In some case warming temperature can induce early flowering affecting pollination and seed production. This can also lead to desynchronization between plant and pollinator species (Freimuth et al., 2022). It has been noted that angiosperm flowering times advance with climate change, but it is unclear whether fruiting dates also vary as a result of moving flowering times, or whether they react to climate change differently or not at all.

D. **Change in Plant height:** As temperature increase, Plant may exhibit vertical growth to seek cooler and moisture rich environment (Reich et al., 2018). There are some significant elements influencing plant growth: Temperature: As the temperature rises, growth quickens. Light: A plant's physiological activities are influenced by the amount, type, and quality of light available. Water: A plant's ability to grow depends on water. The majority of plant issues are brought on by environmental stress, either directly or indirectly. In some circumstances, a plant is directly harmed by unfavourable environmental conditions (such not enough water). Other times, environmental stress weakens a plant, making it more prone to illness or insect assault.

E. **Trichome:** Trichomes are hair like structure found on the leaves, stems and other plant parts. They serve various functions including, protection against herbivores, reducing water loss and reflecting sunlight (Jolivet, 2023). Secondary metabolites, such as terpenoids, flavonoids, and others that can repel, damage, and catch insects and other pests, are secreted by glandular trichomes, providing a variety of plant defenses. They can be found alone or sporadically in groups. They come in a variety of shapes and sizes and can be unicellular or multicellular. They range from tiny protuberances of the epidermal cells to intricate multicellular formations that are branching or stellate. Hair cells could have lived or dead cells. The hairs commonly lose the protoplasm inside of their cells. Climate changes have both direct and indirect impact on trichome formation in plants and on the morphology of trichomes.

F. **Increased trichome density**: Higher temperature and increased UV radiations associated with climate change can stimulate the trichome formation in response to elevated stress levels. This can lead to an increase trichome density on plant surface (Punja et al., 2023). When stem water potential fell, the number of leaves trichomes rose, which increased the amount of visible light that the leaf reflected. Under water stress, cell and leaf growth were constrained, and epidermal cell size and trichome density showed negative relationships.

G. **Change in trichome shape, size and density**: Trichomes have consistently been shown to be a useful phenotypic characteristic for identifying species' evolutionary and taxonomic relationships. Trichome can produce chemical compounds that deter herbivores and pathogens. Morphology, density and dimensions relationships of subtypes of trichomes can be employed to find correlations between trichome characteristics with herbivore feeding intensity and behavior. In response to increased temperature, trichomes may become longer and more branched, maximizing their surface area to enhance cooling effects through increased transpiration (Wang et al., 2021).

H. **Leaf hardening and sclerification:** Climate change can lead to leaf hardening and sclerification in plants. Leaf hardening can refer to the process of leaves becoming tougher and more rigid, while sclerification refers the development of sclerenchyma cells, which are thick walled and provide additional support to the leaf structure. This process can be influenced by several factors related to climate change:

I. **Drought Stress**: increasing temperature and altered precipitation patterns associated with climate change can lead to more frequent and prolonged droughts (Jump et al., 2017). In response, plants may undergo leaf hardening and sclerification as mechanism to conserve water and reduce water loss through transpiration (Salleo & Nardini, 2000). Plant biomass output, quality, and energy are all hampered by drought stress, an unavoidable condition that occurs in many ecosystems with no clear bounds and warning. It is the most significant environmental stress brought on by changes in temperature, light intensity, and rainfall levels.

J. **Heat stress:** Higher temperature can cause heat stress in plants, leading to the development of thicker and tougher leaves (Lipiec et al., 2013). Leaf hardening help protect the underlying tissues from excessive heat and reduce water loss (Wahid et al., 2007). Extreme heat can cause oxidative stress, which damages plant cells and hinders their growth by generating reactive oxygen species (ROS); also, water stress is brought on by increased transpiration rates brought on by high temperatures, which reduce the quantity of water available to crops.

K. **Increased UV radiations**: Climate change can result in higher level of UV radiations reaching the earth surface. Plants and microbes are directly impacted by ultraviolet (UV) radiation, which also changes the way that different species interact with one another. Various effects of UV radiation's three separate bands, UV-A, UV-B, and UV-C, on plants and the microbes that live on them. While UV-A and UV-B primarily influence morphogenesis and phototropism, UV-B and UV-C significantly increase the formation of secondary metabolites.

L. **Cryptic coloration and mimicry:** Changing climate can have significant impact on cryptic colorations and mimicry in plants. These adaptations are crucial for plants to blend it with their surroundings, avoid predations or exploit mimicry to gain benefits (Niu et al., 2018). Climate change can lead to shifts in vegetation patterns and seasonal timing. As a result, plant populations may no longer match their current surroundings, diminishing the effectiveness of cryptic colorations (Delhey & Peters, 2017). E.g., if snow cover can reduce in snowy habitat, plants with white colorations will be less camouflaged. Many plant species have evolved to mimic the appearance of other organisms such as insects or flowers (Jürgens et al., 2015). Climate change can disrupt the synchronization between phenology of mimicking plants and their targets (Forrest, 2015).

2.1.1 Morphological Changes below the Ground:

Climate change can have significant impact on plant parts present below the ground including roots, tubers, rhizomes, and bulbs.

A. **Root system distribution:** Climate change particularly changes in temperature and rainfall pattern can alter soil moisture availability. This can influence root system development and distribution (St. Clair & Lynch, 2010). Plants may develop deeper and more extensive root system in search of moisture in drought-prone region, while in water logged areas, they may develop shallower roots to access oxygen (Ding et al., 2021).

B. **Root length and thickness:** Change in temperature and soil moisture can influence the growth and size of roots. In warmer and drier conditions, plants may develop longer and thinner roots as they search for water and nutrients in the deeper soil layers

(Montagnoli et al., 2012). Conversely, in cooler and wetter conditions, plants may develop shorter and thicker roots to maximize nutrient uptake in shallow soil layers (Montagnoli et al., 2023).

C. **Changes in root exudates composition:** Root exudates are organic compounds releasd by plant roots into the surrounding soil. They provide nutrient to surrounding soil. They provide nutrition to soil microorganisms, influence nutrient cycling, and interact with the rhizosphere (Lamichhane et al., 2023). Climate change particularly elevated CO2 level and altered soil moisture, can affect the composition of root exudates, potentially altering microbial communities and nutrient dynamics in soil (Raza et al., 2023).
D. **Altered root hair proliferations:** Root hairs are tiny, elongated outgrowths of root epidermal cells that increase the surface area for water and nutrient absorption (Adu et al., 2023). Tubular extensions known as root hairs grow from the epidermal cell layer in the differentiation zone. They are essential in increasing the root's surface area, which improves the root's ability to absorb water and nutrients from the soil. Climate change including change in temperature, precipitation, and change in soil moisture, can affect root hairs proliferation. In water stressed conditions plats may develop more hairs to increased water uptake.

2.2 Structural Modifications in Plants due to Climate Change:

Climate change can lead to various structural modifications in plants as they adapt to changing environmental conditions. Here are some examples:

A. **Change in plant height and architecture:** The organization of the plant body in three dimensions is referred to as plant architecture. This covers the branching pattern, as well as the size, shape, and location of leaves and flower organs, for the sections of the plant that are above ground. Rising temperature and changing precipitation patterns can alter plant growth patterns. In response pants may undergo structural modifications such as changes in height, branches, and overall architecture (Prisa & Fresco, 2023). For instance in drought prone areas, plants may become shorter and more compact to reduce water loss and increase water efficiency (Chen, 2023).
B. **Leaf modifications:** Climate change can influence leaf morphology and structure. Some plants may develop thicker leaves to withstand higher temperature and reduce water loss through transpirations (Yu et al., 2023). Additionally leaf size and shape may change to optimize energy capture and heat dissipation. In regions experiencing shifts in temperature and light availability, plants also exhibit change in leaf orientations or the presence of leaf hairs or trichomes on the leaf surfaces.
C. **Modifications in reproductive structure:** Climate change can affect the reproductive structure of plants, such as flowers, fruits, and seeds. Different reproductive techniques have evolved in plants to ensure the survival of their species. As opposed to animal species, which rely almost completely on sexual reproduction, some plant species reproduce sexually while others do so asexually. Pollinators are not necessary for asexual reproduction in plants, although sexual reproduction usually requires them. Flowers are typically the most lavish or potently scented part of plants. Because of their vivid colours, enticing smells, and distinctive shapes and sizes, flowers attract insects, birds, and other species for pollination. Other plants get pollinated via the wind or the water, while some plants self-pollinate.

2.2.1 Thrones, Prickles and Spines Modification in Plants due to Climate Change:

Climate change can also lead to modification in the thrones, prickles and spines in plants. These structures are often used by plants as a defense mechanism against herbivores and other threats (Belete, 2018). One possible modification is an increase in the density and length of the thrones, prickles and spines in plants (Benelli, 2015). Warmer temperatures and changing precipitation pattern can create more favorable conditions for herbivores such as insects or grazing animals (Koulelis et al., 2023). In response plants may develop more pronounced or larger thrones, prickles or spines in response as a way to deter herbivory and protect themselves (War et al., 2012). Additionally, climate change can also impact the chemical composition of these defensive structures. Certain compounds present in thrones, prickles, or spines can act as toxin or deterrent, making them less appealing for herbivores to feed on them (Halpern et al., 2007). Changes in temperature and other environmental factors can influence the production and concentration of these chemicals, potentially leading to modification in the level of plant defense.

2.3 Modification in Bark and Periderm:

Climate change can also lead to modification in the bark and periderm of plants. The periderm is the outer protective layer of the plants, including the cork cambium, cork cells, and phelloderm. These modifications occur due to the changing environmental conditions (Teixeira, 2022). As temperature rise and the drought conditions increase, plants may develop thicker bark to protect themselves from desiccation and excess heat (Marchin et al., 2022). Thicker bark provides insulation and reduces water loss through transpiration. Climate change can stimulate the cork cambium to produce more cork cells, leading to increase in the thickness of the periderm. This can enhance the plants resistance to environmental stress such as heat, fire and herbivory. Change in temperature and moisture level can cause variations in the composition of the periderm.

2.4 Conclusion:

Morphological changes in plants in response to insect pests represent a fascinating and intricate facet of plant-insect interactions. These changes, driven by a plant’s natural defense mechanisms, have evolved over millions of years to help plant withstand the pressures of herbivory. From altering leaf structures and producing secondary metabolites to attracting beneficial insects and enhancing root defenses, plants have developed a diverse array of strategies to cope with insect pests. Understanding these morphological changes is crucial not only for advancing our knowledge of plant biology but also for developing sustainable pest management strategies in agriculture. Furthermore, ongoing research in this field continues to uncover the intricacies of plant-insect interactions, shedding light on the molecular and genetic mechanisms underlying these morphological changes.

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3. Physiological Changes in Plants in Response to Insect Pests

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Abstract:

Insects and plants are diverse groups with complex relationships that can be classified as mutualistic, antagonistic, or commensalistic. Fossil records and molecular clock concepts can reconstruct historical interactions between plants and insects. Plants produce secondary metabolites to protect themselves from herbivores, and insect chemoreceptors help them recognize specific primary and secondary metabolites in plants. Understanding these secondary metabolites helps quantify plant insect interactions. Plants can be damaged by herbivorous insects, which release volatile compounds called herbivore-induced volatile plants (HIPVs), which pollinate host plants and attract natural enemies. Reactive oxygen species (ROS) and plant hormone signaling are essential components in plants' communication system, enabling them to respond to environmental factors. Insect herbivory significantly impacts photosynthesis, with chloroplast reactions producing various forms of ROS. Stomata play a crucial role in interactions between plants and herbivores, with changes in stomatal dynamics affecting cellular, organismal, and community levels. Overall, the intricate relationships between plants, microorganisms, and environmental factors play a vital role in the overall health and productivity of agricultural systems.

Keywords:

Secondary metabolites, host plants, photosynthetic alterations, ROS, herbivory.

3.1 Introduction:

Insects and plants are highly diverse groups known for their ability to exploit many niches, from the desert to the arctic zone, and also occupy almost all plant species**.** The total number of multicellular organisms is approximately half that of plants and insects. Traditionally, plant-insect interactions have been classified as mutualistic, antagonistic, or commensalistic (Calatayud et al., 2018). It has taken a long time for insects and plants to develop complex relationships. In a recent study, it was shown that fossil records, which contain different types of signals, can be used to reconstruct historical relationships between plants and insects (Schatz et al., 2017). According to Schatz, et al. 2017, phylogeny and molecular clock concepts also provide robust assumptions about the age of insect lines and their relationship to their hosts. A mutualistic relationship has evolved between plants and insects through the process of pollination. Because organisms are part of food webs, direct and indirect interactions between members of an ecosystem are common.

A diverse array of secondary metabolites is produced by plants in order to protect themselves from herbivores (Divekar et al., 2022). The study of secondary metabolites and their role in insect traits has greatly benefited understanding and quantifying plant insect interactions. The majority of insects reject non-hosts or plants that might be harmful to them. Molecular interactions between specific ligands and chemoreceptors play a key role in insect host adaptation and speciation (Nishida, 2014).

Plants can be damaged by herbivorous insects that release volatile compounds called herbivore-induced volatile plants (HIPVs), which pollinate host plants and attract natural enemies. Insects and arthropod predators are among these enemies (Guo & Wang, 2019). As a result of the use of synthetic pesticides and fertilizers in crop production, the environment as well as the health of humans have been negatively affected. Plant diseases are controlled through biocontrol, which is the most eco-friendly used technique. Host plants and Trichoderma species engage in a mutually advantageous symbiotic relationship, where both gets benefit. Trichoderma-based products have been on the market as biocontrol agents (BCAs) to effectively manage various crop pathogens, as well as biofertilizers or growth stimulants that foster plant growth (Alfiky & Weisskopf, 2021). There are several important role of secondary metabolite, that help the cabbage root fly to recognize and locate suitable hosts (Ahuja et al., 2011).

The stomata of plants are proving to be important mediators of interactions between plants and herbivores. Herbivores produce oral secretions that contain enzymes and phytohormones that trigger the closure of the stomata in response to herbivory (Lin et al., 2022). The changes in stomatal dynamics caused by herbivory may affect cellular, organismal, and even community levels since they are linked to interrelated physiological processes.

3.2 Plant Perception and Signalling:

Plants communicate constantly with their environment through volatile organic compounds (VOCs). In order to achieve maximum fitness, plants and the organisms they interact with rely on this communication to coordinate growth, development, defence, propagation, and reproduction (Bouwmeester et al., 2019). Insects use visual cues for locating plants over long distances, especially those that can disperse over long distances (Grunseich et al., 2019). During plant-insect co-evolutionary arms races, plant volatiles play an invisible role. In the ecosystem, they are involved in a variety of Tri-trophic interactions mediated by plants. Insect's advanced olfactory systems enable them to detect and process these complex environmental cues (Binyameen et al., 2021). Species-specific compounds or specific ratios of ubiquitous compounds will be used by insects to recognize a host plant. Phytophagous insects detect volatile organic compounds (VOCs) through olfactory sensilla on their antennae, which provide information about food, mates, and oviposit sites (Riolo et al., 2012). As a direct resistance agent, molecules from volatile plants have a strong ability to penetrate wound sites and act as direct agents of healing (Zhang et al., 2023).

Jasmonic acid (JA), along with its precursors and derivatives known as jasmonates (JAs), play a crucial role in orchestrating plant reactions and protective mechanisms in response to both biotic and abiotic stress factors (Wang et al., 2021).

Hormone metabolism components and signaling have provided a greater understanding of how plant growth and physiology are regulated (Jang et al., 2020). A study is underway to investigate whether JA signaling influences root exudation in a way that can enhance plant tolerance to biotic stress through the recruitment of microbes (Carvalhais et al., 2017).

A phytohormone is a signal molecule produced by the plant that regulates gene expression and controls its growth and development (Curaba et al., 2014). There are various phytohormones, growth regulators (Abscisic acid and ethylene) stress tolerance (Salicylic Acid and Jasmonic Acid) (Tiwari et al., 2017). Herbivores and pathogenic microbes are effectively and efficiently responded to by the plant when inducible immune responses are activated (Caarls et al., 2015). When an intruder is detected, the organism accumulates signaling substances like salicylic acid (SA) and jasmonic acid (JA) and their related compounds. These molecules play a crucial role in triggering subsequent defensive reactions.

3.3 Induced Defence Mechanisms:

Plants cannot evade the challenges posed by living threats like pathogens, parasites, herbivores, as well as non-living factors such as drought, floods, high or low temperatures, UV radiations, salinity and nutrient deficiencies. Through a combination of structural characteristics and biochemical reactions, which may or may not be present throughout the life of the plant, plants defend themselves against pathogen attack and continue to grow and yield in significant quantities (Shittu et al., 2019). Numerous subcellular structures are essential for orchestrating defense signaling in plants, with key contributions from organelles such as chloroplasts, mitochondria, vacuoles, and the endoplasmic reticulum (ER) (Iqbal et al., 2021). Secondary metabolites in plants are compounds that aren't crucial for their fundamental growth and development. However, they frequently serve significant functions in protecting against herbivors, pathogens, and environmental stressors.

The phenylpropanoid pathway is a typical route for generating these secondary metabolites (Sharma et al., 2019). This pathway produces compounds like flavonoids, lignins and phenolic acids. Another pathway is the terpenoid pathway, responsible for producing compounds have roles in defense against herbivores (Chen et al., 2018).

As part of the regulation of a wide range of physiological processes in plants, jasmonate phytohormones (JAs) are derived from lipids. These phytohormones regulate growth, development, abiotic stress tolerance, and insect and pathogen defences. JAs are essential for the digestion and benefiting of prey by the carnivorous plants (Pavlovič & Mithöfer, 2019). An inducible systemic acquired resistance (SAR) confers a broad spectrum of immunity against secondary infections beyond the site of infection itself. Researchers have provided a first clue to understanding the molecular mechanism behind these phenomena through studies of wheat and barley NPR1 homologs genes (WANG et al., 2019).

In plants, salicylic acid (SA) is known as a phytohormone that regulates seed germination, photosynthesis, respiration, flowering, and senescence (Rivas-San Vicente & Plasencia, 2011). SA also activates plant defence responses against extreme temperatures, ozone pollution, UV irradiation, heavy metals, droughts, and salinities.

3.4 Photosynthetic Alteration:

Agricultural and indigenous plants encounter various biological challenges stemming from living organisms, spanning from viruses to mammals. Numerous of these detrimental factors influence the process of photosynthesis, either by modifying its core functions such as primary photochemical reactions, electron transport, and Calvin cycle, or by impeding gas exchange and diminishing the available surface area for photosynthesis. Pathogens, including fungi, bacteria, and viral agents, as well as animal pests, on average, lead to a 15% and 18% reduction in crop yield, respectively (Barón et al., 2011) .

Photosynthesis, a vital process in plant physiology, plays a vital role in defending plants contrary to biotic stress. When plants interact with pathogens and pests, it often leads to changes in sugar metabolism and source-sink relationships. These alterations can serve as part of the plant's defense mechanisms, limiting nutrient availability to the invaders. Alternatively, pests may manipulate plant metabolism for their value (Pérez-Bueno et al., 2019). Environmental stressors, such as salinity or salt stress, can have detrimental effects on the process of photosynthesis in plants. These modifications in the cell wall can, in turn, have an impact on the overall structure of plant leaves, ultimately leading to a decrease in the efficiency of photosynthesis (Dabravolski & Isayenkov, 2023).

Phytophagous insects are a significant challenge in agriculture, leading to substantial economic losses. While synthetic insecticides have been effective, their efficacy has diminished over time due to various factors:

3.4.1 Plant Primary Metabolism in Response to Insect Herbivory:

Photosynthesis, the primary process through which green plants generate carbohydrates, plays a pivotal role in the carbon allocation response to herbivory. The adjustment of photosynthesis and carbon fixation in the face of herbivory has generated divergent theories. Firstly, it's suggested that photosynthetic activity might increase in response to herbivory. This could occur because the synthesis of defensive compounds relies on carbon fixation. Furthermore, plants can respond to the loss of leaf area by increasing photosynthesis in the remaining parts of the plant. In certain situations, insects may influence the plant’s metabolic processes to encourage carbon fixation for their own advantage (Appel et al., 2014). Conversely, another theory posits that photosynthetic activity could decrease. This could be due to the energy-intensive nature of producing the photosynthetic machinery. In exchange for enhanced defensive substances, there could be a potential compromise in the efficiency of photosynthesis (Coppola et al., 2013). Additionally, localized insect feeding can lead to leaf senescence and reduced photosynthesis. Reduced carbon assimilation might limit the carbohydrates available for herbivores.

In plant-herbivore interactions, plant amino acids play a dual role. They function as crucial nutrients necessary for the growth of plants, while also serving as building blocks for the synthesis of various defensive compounds in plants. When plants are attacked by herbivores, they are believed to respond by enhancing their production of amino acids (Appel et al., 2014). Plants that are infested by herbivores are believed to increase their amino acid production in order to facilitate the creation of protective substances.

While plants increase amino acid production for defense, they also aim to restrict herbivores' access to free amino acids. This limitation is important because herbivores depend on free amino acids as nutrients (Steinbrenner et al., 2011).

3.4.2 The Central Role of ROS Signaling in Plant–Insect Interactions:

Reactive oxygen species (ROS) and plant hormone signaling are crucial components of the communication system that enables plants to respond to various environmental factors. It's not surprising, therefore, that ROS play a well-established role in how plants react to insects, including aphids. Insect herbivory significantly impacts photosynthesis, both through physiological mechanisms and changes in the expression of genes related to photosynthesis (Fujita et al., 2006).

In the presence of light, photosynthesis serves as the primary generator of ROS, where chloroplast reactions yield different types of ROS, such as singlet oxygen, superoxide, and hydrogen peroxide, even when conditions are optimal (Nabity et al., 2009).

ROS accumulation in plants is not immediately evident after feeding by insects like *S. littoralis* or *Tetranychus urticae*. It is detected 24 hours after caterpillar damage or leaf yellowing. Arabidopsis experiences a delay in ROS accumulation after phloem-feeding aphids, with up-regulation of genes related to oxidative stress.

This suggests that ROS accumulation may not be essential for redox signaling pathways, but can be activated through secondary events like increased cellular antioxidant turnover rates (Fujita et al., 2006).

3.4.3 Roles for ROS and Antioxidants in Plant Defenses against Insect Herbivores:

Research shows that reactive oxygen species (ROS) are crucial for plant defense responses against insect herbivores. Insects have evolved mechanisms to detoxify these radicals within their gut, with studies showing a connection between tannin tolerance and gut antioxidant function. Tannin-tolerant *Orgyia leucostigma* and tannin-sensitive *Malacosoma disstria* caterpillars exhibited higher levels of antioxidant enzyme activity compared to tannin-resistant species. However, the addition of dietary ascorbic acid mitigated this effect in *Orgyia leucostigma* but not in tannin-sensitive *Malacosoma disstria* (Barbehenn et al., 2001).

Furthermore, *Orgyia leucostigma* exhibited notably higher levels of glutathione within its midgut compared to its diet, suggesting active secretion of this compound by this species. Furthermore, electron paramagnetic resonance spectroscopy (EPR) identified fluctuating quantities of semiquinone radicals derived from tannins and ascorbyl radicals within the midguts of these caterpillar species.

In essence, these findings suggest that ROS are involved in inducing plant defenses against herbivorous insects, and the differences in the antioxidant capacities of insect guts may influence their ability to tolerate specific plant compounds like tannins.

3.4.4 Chloroplast's Integration of ROS and Hormonal Signaling in Response to Insect Herbivores:

Extensive research has confirmed the vital functions of plant hormones like JA, SA, and ethylene in protecting plants from herbivorous insects. These hormones are major players in the plant's response to herbivore attack (Kessler & Baldwin, 2002). Extensive research has revealed intricate crosstalk between reactive oxygen species (ROS) and hormonal signaling pathways in plants, influencing their responses to various stressors. This communication involves a wide range of plant hormones, such as auxin, abscisic acid, jasmonate, salicylate, ethylene, gibberellins, and cytokinins. ROS, with singlet oxygen, superoxide, and hydrogen peroxide (H_2O_2), interact with these hormonal pathways, coordinating plant development and stress responses (Mittler et al., 2011).

Additionally, studies have unveiled connections between hormonal signaling and light signaling pathways related to the photosynthetic electron transport chain. In high-light conditions, this chain generates oxidants like singlet oxygen, superoxide, and H_2O_2, which further contribute to the intricate signaling network in plants (Pastori & Foyer, 2002). This interplay between ROS, hormones, and light signaling is crucial for plants to adapt and respond effectively to environmental challenges, including herbivore attacks and varying light conditions. These elements are integral components of the light signaling pathways within chloroplasts, and research has demonstrated their connection to both the fundamental and adaptive immune responses in plants.

3.5 Systemic Acquired Resistance:

Plants develop heightened resistance to pathogen attacks after being infected by necrotizing pathogens, known as systemic acquired resistance (SAR). SAR is a form of plant memory that allows plants to recall past experiences of pathogen encounters, triggering their defense mechanisms more quickly and effectively when confronted by a pathogen for the second time. SAR has been recognized since the early 20th century, and research has shown diverse induced disease resistance processes in plants (Conrath, 2006).. Pathogens that produce tissue necrosis can cause a hypersensitivity response or illness symptoms, activating SAR. SAR is famous for establishing stronger resistance in plant organs that haven't been immunized far from the infection site. SAR has broad-spectrum efficacy against various pathogens, providing long-lasting protection lasting weeks to months or even a season (Ryals et al., 1996). SAR's functioning implies that plants have a form of "memory" that allows them to recall past experiences, making it a prime example of plant memory and signal transduction (Yakura, 2020).

3.5.1 Systemic Acquired Resistance Signalling:

Early grafting studies demonstrated that an infected plant's primary leaf emits a systemic signal that induces systemic acquired resistance (SAR) in remote tissue (Kessmann et al., 1994). The exact identity of this long-distance signal was initially unclear, with some suggesting salicylic acid as the translocated signal (Jirage et al., 1999). Recent studies using Arabidopsis mutants suggest that wild-type DIR1 may contribute to the production and transmission of this mobile SAR signal. In Arabidopsis mutants with defects in putative lipases, SAR activation is compromised, suggesting a role for lipid signaling. H_2O_2 has been proposed as a signaling role in SAR. Recent studies have revealed that the release of gaseous methyl salicylate, a volatile compound generated within tobacco leaves, acts as an airborne signal, inducing disease resistance in both affected and unaffected tissues, as well as in nearby plants (Ryals et al., 1996). The long-distance signaling involved in SAR is complex and may involve various signals, with the specific contribution varying depending on the plant species.

3.5.2 Salicylic Acid: Endogenous Signal for SAR:

Salicylic acid (SA) is known to play a critical role in generating systemic acquired resistance (SAR) in distant plant tissues, despite the fact that the precise long-distance signal responsible for SAR is yet unknown. Transgenic tobacco and Arabidopsis plant research provided the first strong support for this theory. These plants were genetically modified to constitutively express a bacterial SA hydroxylase, which prevented them from accumulating significant amounts of SA. As a result of the SA signal being broken, they did not develop systemic resistance when exposed to necrotizing infections (Delaney et al., 1994; Gaffney et al., 2018). The role of SA as a crucial signal in SAR has been further validated by more recent study using Arabidopsis mutants that are impaired in either SA production or SA signaling. Additionally, it was discovered that excessive SA synthesis increased the disease resistance of transgenic tobacco and Arabidopsis plants.(Lawton et al., 1996). These findings collectively emphasize the pivotal role of SA in SAR, even though the exact nature of the long-distance signal involved in SAR remains a subject of ongoing investigation.

3.5.3 Systemic Acquired Resistance (SAR), Activators:

Systemic acquired resistance (SAR) is a well-documented phenomenon in plants, and priming, which leads to enhanced activation of defense responses, is a crucial component of this process. In the primed state, plants acquire the ability to activate their defense mechanisms more rapidly and effectively when faced with biotic or abiotic stress (Lawton et al., 1996). Understanding the primed state at molecular, biochemical, and physiological levels contributes to a deeper comprehension of signal transduction in plants and opens doors to harnessing the natural defense capabilities of plants in practical agricultural settings (Thulke & Conrath, 1998). Researchers like Kauss and Conrath have made valuable contributions to our understanding of priming and SAR, which enables plants to prepare for future battles and mount quicker and more effective defense responses when faced with subsequent pathogen attacks (Conrath, 2006; Kauss et al., 1992). This heightened readiness contributes significantly to their overall resistance against pathogens.

3.6 Biotechnological Implications and IPM Strategies:

Biotechnology has significantly advanced plant resistance to insect pests, revolutionizing agricultural practices. This field has employed various strategies, including gene transformation, genome editing, RNA interference, marker-assisted selection, anther culture, embryo culture, protoplast fusion, and somaclonal variations (Talakayala et al., 2020). Transgenic crops have been developed to express insect-resistant genes, reducing the reliance on chemical pesticides.

Insect-resistant crops, such as cotton and maize, have become widely integrated into global agriculture, leading to a decrease in pesticide use and lowered production costs (Brookes & Barfoot, 2005; Toenniessen et al., 2003).

Plant lectins, proteins that provide resistance against phytophagous insects, have been explored in various crops, offering a natural defense mechanism against pests. Lectins are carbohydrate-binding proteins present in numerous plant species, particularly in families such as Solanaceae, Fabaceae, and Poaceae. They have entomotoxic properties, discouraging a wide array of insects and animals that consume plants. Recent developments have seen the emergence of insect-resistant plants, paving the way for the use of plant lectins in pest management strategies (Caroline et al., 2022).

Intrinsic defenses have also been discovered through biotechnology research, which are integral to the plant's inherent defense mechanisms and can be modifiable for increased efficacy. Plants have evolved a sophisticated and adaptable defense system in response to herbivore attacks, which can be constitutive or induced (Klauser et al., 2016). Induced responses in plants come at some metabolic costs but are crucial for mitigating immediate stress, as most chemicals are produced in response to herbivore attacks.

RNA interference (RNAi) technology has the potential to control a wider range of insects, including sap-sucking insects, which transgenic crops have struggled to manage. RNAi technology employs two main delivery methods, HIGS (host-induced gene silencing) and SIGS (spray-induced gene silencing), to ensure that the target genes are silenced in the pest population (Christiaens et al., 2020). However, there are challenges in efficiently delivering dsRNA to insects and the inherent instability of RNA in unfavorable environmental conditions limit the effectiveness of SIGS approaches (Liu et al., 2020). Overall, biotechnology has the potential to provide eco-friendly solutions for managing agricultural pests and protecting crop yields.

3.7 Future Directions and Conclusion:

The investigation into the physiological alterations that plants undergo in response to insect pests is a vital realm of inquiry with extensive implications for agriculture and pest control. The forthcoming paradigm of pest management revolves around integrated methods. Scientists should concentrate on forging comprehensive IPM strategies that encompass physiological insights. This may encompass amalgamating biological control practices, pest-resistant plant varieties, and precision pesticide applications grounded in pest-plant interactions. By employing genomics, transcriptomics, proteomics, and metabolomics can yield profound insights into plant reactions to insect pests. Given climate change's impact on pest dynamics, forthcoming research should delve into how shifting climatic conditions impact plant-insect interplays. This encompasses scrutinizing how modified temperature and precipitation patterns influence pest lifecycles and plant responses.

Biotechnology proffers promising avenues for heightening plant resilience to insect pests. Sustained exploration in this domain should contemplate the development of genetically modified plants endowed with enhanced resistance traits. Also, research into the allelopathic effects of plants on insect pests can provide sustainable pest control options.

The comprehension of the physiological adaptations in plants when confronted with insect pests holds pivotal importance for sustainable agriculture. Subsequent research should pivot towards multidisciplinary approaches, integrating technological innovations and cognizant of the evolving challenges posed by climate change. This wisdom will empower us to formulate efficacious, eco-friendly pest management strategies, thus securing food sustainability for posterity.

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4. Role of Biosensors-Based Detection in Plant Protection

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Abstract:

Plant pathogen detection is recognizing microscopic organisms such as bacteria, viruses, and fungi in quick reaction settings at nurseries, natural landscapes and micropropagation stage in infected plant tissue. Early detection provides opportunity to farmer to take proper measurement and save the crops from complete failure. For plant protection or disease control, simultaneous detection of all the present phytopathogenic microbes with quick and high accuracy is of great importance in all areas related agriculture and environmental safety. In this regard, biosensors technology in plant disease detection in broad-spectrum has advantage like lessening the investigation time and sensitivity through automation and integrating multiple processes in a single piece of equipment. The use of different types of biosensors based on colorimeter, electrochemical signal, lights emissions and nanomaterials for pioneering and sensitive biosensing systems for the recognition of pathogens is also shown. The untamed potential of various biosensors with some limitations for plant disease detection has been briefly reviewed in this article.

Keywords:

Biosensors, Microbes, Nanomaterial, Food safety, Environment, Signal processing.

4.1 Introduction:

Biosensors are devices that detect and measure biological responses or analytes, such as specific proteins, enzymes, antibodies, or DNA, and convert them into measurable signals. They are widely used in various fields, including medical diagnostics, environmental monitoring, food safety, and biotechnology research.

4.1.1 Biosensors typically consist of three main components:

A. **Biological recognition element:** This is a biomolecule that interacts selectively with the target analyte. It can be an enzyme, antibody, DNA/RNA, or whole cells. The biological recognition element provides the specificity of the biosensor by binding to the target analyte.
B. **Transducer:** The transducer converts the biochemical signal generated by the interaction between the biological recognition element and the analyte into a

measurable signal. The transducer can be optical, electrochemical, piezoelectric, or thermal, depending on the type of biosensor.

C. **Signal processing system:** This component amplifies, analyses and displays the signal generated by the transducer, allowing for quantitative measurement and analysis of the target analyte.

4.1.2 Biosensors in plant protection with examples:

Biosensors play an important role in plant protection by enabling rapid and sensitive detection of pathogens, pests, and environmental factors that can affect plant health. Here are a few examples of biosensors used in plant protection:

A. **Pathogen detection biosensors:** Biosensors can be designed to detect specific plant pathogens, such as bacteria, fungi, and viruses. For example, DNA-based biosensors can use specific DNA probes to identify the presence of pathogen DNA in plant samples. These biosensors can aid in early detection and monitoring of diseases, allowing for timely interventions to prevent or control the spread of pathogens.
B. **Pest monitoring biosensors:** Biosensors can also be used to monitor insect pests that can damage crops. Some biosensors utilize pheromones or volatile organic compounds emitted by pests to attract and trap them. These biosensors can help in monitoring pest populations, identifying infestation hotspots, and implementing targeted pest control measures.
C. **Environmental biosensors:** Biosensors can be employed to monitor environmental factors that impact plant health, such as soil quality, nutrient levels, and water quality. For instance, biosensors can measure the concentration of specific ions or nutrients in soil or water samples, providing valuable information for optimizing fertilization practices and ensuring proper irrigation.
D. **Toxin detection biosensors:** Certain plant pathogens produce toxins that can harm plants. Biosensors can be designed to detect these toxins, enabling early identification and mitigation of toxin-mediated damage. For example, biosensors can be developed to detect mycotoxins produced by fungi, which can contaminate crops and pose health risks.
E. **Plant stress biosensors:** Biosensors can be utilized to monitor plant stress factors such as drought, salinity, or temperature fluctuations. These biosensors can measure specific physiological or biochemical responses in plants, such as changes in leaf water potential or the accumulation of stress-related proteins or metabolites. By monitoring plant stress levels, appropriate measures can be taken to mitigate the impact and optimize plant growth.
F. **Pesticide residue biosensors:** Biosensors can be used to detect and quantify pesticide residues on plants. These biosensors can help farmers ensure that pesticide application is within safe limits and avoid potential harm to human health and the environment. Various biosensing platforms, such as electrochemical and optical biosensors, have been developed to detect specific pesticides or pesticide classes in plant samples.

These examples highlight the diverse applications of biosensors in plant protection, helping farmers and researchers detect and respond to threats effectively.

Biosensors offer the advantage of rapid and sensitive detection, allowing for timely interventions and more precise plant protection strategies.

4.2 Diagnostic Methods for Plant Pathogens:

Monitoring plant health and implementing an effective integrated disease management (IDM) strategy depend on the early detection of plant pathogens. Differentiating between causative species is crucial because numerous fungal infections alter plants in ways that are similar to one another during disease development. Vulnerable crops frequently experience more obvious signs, such as morphological and color changes, particular necrotic patches, and even the loss of the plant's stem or leaves. However, understanding latent infection with no obvious signs is also essential to ensure fully informed care. (Oerke, 2020).

Visual crop inspection, which requires a skilled grower or pathologist, is the oldest traditional method that is still widely employed for disease and potentially pathogen diagnosis. By the time a visual diagnosis is made, the pathogen will probably have established itself in host populations. The development of earlier pathogen detection techniques with higher sensitivity, accuracy, and identification speed has therefore received considerable attention. Enzyme-linked immunosorbent assays (ELISA), polymerase chain reactions (PCR), and loop mediated isothermal amplification (LAMP) tests have been the three main types of molecular assays used up to this point, all of which are protein- or nucleic acid-based technologies. These widely used methods do have some drawbacks, such as lengthy diagnostic times, difficult sample preparation steps, carrying the sample from the field to specialized laboratories, and the requirement for trained professionals, despite improvements in sensitivity and specificity to particular target pathogens.

As a result, the need for an in-field diagnostic procedure that is more rapid reliable, especially sensitive, and precise has increased. Such "point-of-care technology" might be created by utilizing the primary properties of the electrochemistry or optical. With a quick reaction time, low-cost on-site trials, and no need for interpreting data skills from the user, this approach improves certain aspects of bioassays.

4.3 Biosensor Technologies for Plant Pathogen Detection:

In several research disciplines, such as monitoring the environment, the detection of airborne diseases, the real-time detection of blood-related components and pathogens, and the detection of pesticide residues in foods and beverages, biosensors have emerged as innovative detection techniques. (Liu *et al.*, 2018).

4.3.1 Affinity Biosensors:

Compared to the non-specific nanoparticle-based biosensors, inclusion of a bio-recognition element can greatly increase the specificity of the sensor. Consequently, other types of biosensors have been developed and among them affinity biosensors are popular. In affinity biosensors, the sensing is achieved based on the reaction of the bio-recognition element and the target analyte **(**Sadanandom and Napier (2010)**).** Affinity biosensors can be developed using antibody and DNA as recognition elements.

A. Electrochemical Biosensors:

An electrochemical biosensor consists of two core components: a molecular recognition layer and an electrochemical transducer, which converts biological data into an electrical signal that can be displayed (Ronkainen *et al*., 2010).

This type of biosensor may detect target pathogens in a variety of environments, including air, water, and seeds on platforms such as greenhouses, in-field, and in postharvest storage vessels (Fang and Ramasamy, 2015). In the meantime, the primary premise of DNA-based biosensors is hybridization or hydrogen bonding between a target DNA sequence and a DNA probe sequence immobilized on a sensing platform. A DNA target sequence and a DNA probe sequence that is mounted on a sensing platform establish a hydrogen bond, which is the fundamental working principle of DNA-based biosensors. A DNA probe is a piece of DNA that has a nucleotide sequence unique to an important chromosomal region. Despite the fact that DNA-based biosensors can measure the quantity of pathogens down to a single cell, DNA degrades quickly in the environment, lowering its sensitivity. Therefore, techniques to increase the sensitivity of this class of biosensor have included the development of nano-structured materials with excellent chemical or electrical properties to enrich the target sequences and to amplify the observed signal. These have primarily included gold, silver, or cadmium sulfide nanoparticles with well-developed biological and chemical characteristics.

These serve as substrates for DNA attachment on the sensor surface, boosting the amount of immobilized DNA and acting as signal amplifiers, enhancing accuracy, sensitivity, and speed of diagnosis. The detection of a particular electroactive indicator or the identification of a signal produced by the most electroactive DNA base serves to characterize the hybridization process between the target DNA sequence and the DNA probe. (Asal *et al*., 2018)

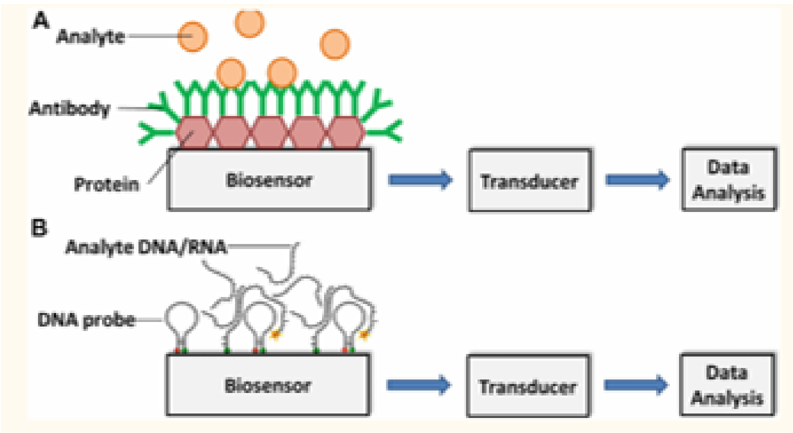

Figure 4.1: Schematic representation of an (A) antibody-based and (B) DNA/RNA-based biosensor for analyte detection. Adapted with permission from Fang and Ramasamy (Fang and Ramasamy, 2015).

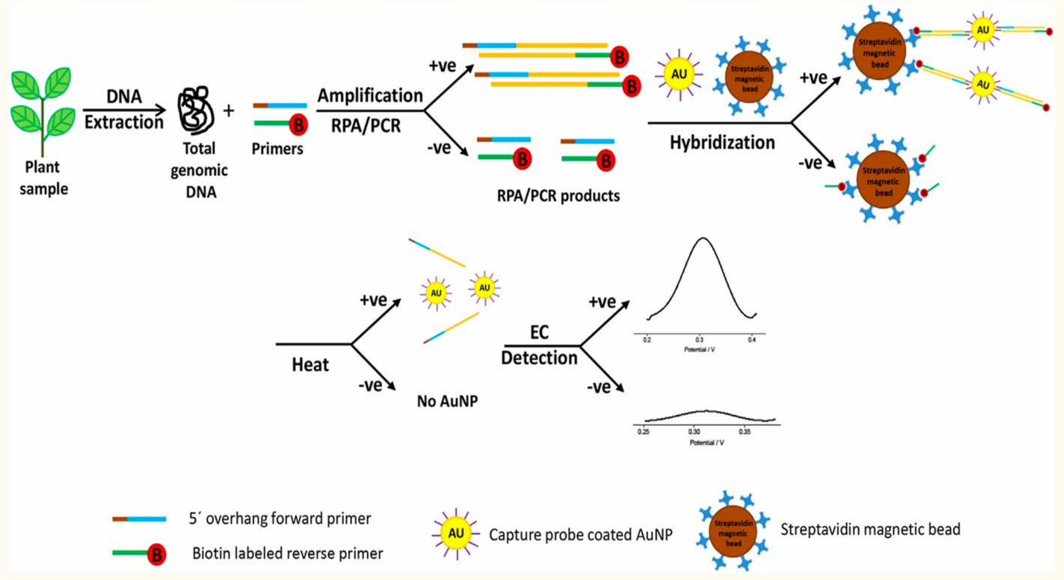

Figure 4.2: Schematic explanation of the DNA based electrochemical bioassay for plant pathogen detection. Adapted with permission from (Lau *et al.*, 2017). EC stands for electrochemical detection and AuNP for gold nanoparticles.

B. Bacteriophage-Based Biosensors:

Bacteriophage is a virus, composed of protein capsid that encapsulates a DNA or RNA genome. It is also emerging as a promising alternative for pathogen detection due to its high sensitivity, selectivity, low cost and higher thermostability [108–110]. Upon the interaction between the bacteriophage and the target analyte, the impedance of charge transfer reactions at the interface changes which is used as a signal for detection. The advantages of using bacteriophage as the recognition element for biosensors are its high selectivity and low cost of the phage. Furthermore, compared to the antibody-based sensor, bacteriophage-based sensors are more thermostable which allows the detection in different temperature ranges and longer shelf life. Bacteriophage-based biosensors are also capable of differentiating the live and dead bacterial pathogens which decreases the false positive signals during measurement. Apart from that, bacteriophage-based sensor can only be fabricated for detection of bacteria rather than fungi and viruses which severely limits its application for the majority of crops that are affected by fungal pathogens.

C. Optical Biosensors:

Optical biosensors measure the interaction between a target analyte and ligand using a light source, an optical transmission medium, an immobilized biorecognition element and a signal detection system. Ultimately, change in amplitude, phase, and frequency of the given light in response to physicochemical conversion (change) generated by the biorecognition process is measured (Ray *et al.*, 2017). Among optical biosensors developed for plant pathogen detection, colorimetric biosensors, fluorescence-based assays-, and surface plasmon resonance-based biosensors are the most common.

Colorimetric biosensors are probably the widest spread tools that allow the user immediate detection of pathogenic microorganisms in the small number of samples just within 10–15 min via a color change. This type of sensors is widely available in the market.

Fundamental principle of fluorescence-based immunoassays relies on the target molecules or antibodies, which are labelled with fluorophores or fluorochrome molecules, producing light during the biological recognition process.

Surface plasmon resonance-based biosensors are predominantly used in optical biosensing techniques with the advantages of label-free, real-time and highly accurate detection (Homola, 2008; Sina *et al*., 2014). The devices contain a sensor chip that is a surface constructed of a metal, such as gold, within two layers comprised of glass and a liquid. The analyte flows over the surface of the chip entering through the bottom or liquid layer and binds with the immobilized ligand that illuminates a light signal that is detectable at a specific angle. The generated signal is then observed with a surface plasmon resonance sensorgram (Damborsky *et al*., 2016).

4.3.2 Biosensor Platforms Based on Nanomaterials:

Nanoparticles display fascinating electronic and optical properties and can be synthesized using different types of materials for electronics and sensing applications. For biosensing application, the limit of detection and the overall performance of a biosensor can be greatly improved by using nanomaterials for their construction. The popularity of nanomaterials for sensor development could be attributed to the friendly platform it provides for the assembly of bio-recognition element, the high surface area, high electronic conductivity and plasmonic properties of nanomaterials that enhance the limit of detection. Various types of nanostructures have been evaluated as platforms for the immobilization of a bio-recognition element to construct a biosensor. The immobilization of the biorecognition element, such as DNA, antibody and enzyme, can be achieved using various approaches including biomolecule adsorption, covalent attachment, encapsulation or a sophisticated combination of these methods. The nanomaterials used for biosensor construction include metal and metal oxide nanoparticles, quantum dots, carbon nanomaterials such as carbon nanotubes and graphene as well as polymeric nanomaterials.

Quantum dots (QD) have also been used for biosensor construction for disease detection (Frasco and Chaniotakis (2009)). Due to their unique and advantageous optical properties, they have been used for disease detection using fluorescence resonance energy transfer (FRET) mechanism (Algar *et al*. (2018)), which describes energy transfer between two light-reactive molecules.

4.4 Conclusion:

Traditional and conventional diagnostic instruments are quickly being replaced by nano biosensing technologies and gadgets. These accessible, quick, highly sensitive, and specialized technologies for plant pathogen detection in the field will soon find widespread use with further optimization for usage in a variety of situations. Utilizing them will probably significantly reduce the frequency and quantity of chemical applications to crops both before and after harvest, as well as the costs associated with on-farm production and the loss of quality and yield due to disease. Multiplexing will be the focus of future research to improve these nano biosensors and allow for the simultaneous detection and surveillance of numerous disease-causing bacteria.

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5. Botanical Insecticides and their Potential to Combat Insect Pest

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Abstract:

The use of agrochemicals has increased recently in order to boost food production for a population that is rapidly expanding on a global scale. However, the careless use of these chemicals, particularly pesticides, has resulted in the build-up of toxic residues in food, soil, air, and water. In turn, this has prompted pests to evolve resistance. The necessity to generate more food sustainably and reliably to fulfill the increasing demand has triggered a quest for natural substitutes to conventional agrochemicals. These alternatives should bolster food security without jeopardizing human health or the environment. Compounds derived from plants possess significant potency, featuring various distinct mechanisms of action, all while maintaining a relatively harmless profile towards unintended organisms. However, challenges like limited stability and technological hurdles hinder the widespread adoption of these plant-based chemicals for pest control. Despite the advantages and disadvantages, the registration and commercialization of botanical insecticides encounter obstacles in India. Issues such as volatile extracts, high costs linked to toxicological assessment, and intricate regulatory approval processes impede their widespread use. While synthetic pesticides are easily accessible in India, it remains imperative to establish regulations for botanical insecticides. This regulatory framework is essential to address the foremost problems associated with their registration and marketing.

Keywords:

Agrochemical, Environment, Residues, Botanicals, Management.

5.1 Introduction:

Insects, diseases, and unwanted plants are responsible for approximately 35% of total agricultural productivity losses on a global scale. In regions with limited resources for pest management, yield reductions can exceed 50%. The combined actions of insects, pests, and pathogens can even lead to complete eradication of crops. Aside from safeguarding crop output and enhancing harvests, ensuring food security hinges on effective crop protection. While Integrated Pest Management (IPM) has gained traction in developed nations, pesticides continue to be commonly employed to control pest populations (Farrar *et al*., 2016). The utilization of synthetic pesticides has risen in both advanced economies and developing countries. Traditional and subsistence farmers still heavily rely on plant-based solutions for pest management. This tradition dates back to ancient times in civilizations such as China, Greece, and India. According to a study conducted in 2018, botanical products are used by as much as one hundred percent of farmers in certain parts of Zimbabwe and Uganda (Dougoud *et al*., 2018).

Across the globe, approximately 2500 plant species from 235 plant families have been documented for their potential in biological pest control (Makaza and Mabhegedhe, 2016; Roy *et al*., 2016). The insecticidal compounds derived from plants are termed botanical insecticides. Plant-based pesticides have received a great deal of attention since the 1980s, making up more than 20 per cent of research articles with an insecticide-specific focus. Common examples of botanical insecticides frequently used include rotenone, sabadilla, nicotine, pyrethrins, ryania, neem, d-limonene, and linalool (Isman, 2020).

5.2 Sources of Botanical Pesticides:

Botanical insecticides can be generated through plant extracts, various essential oils, or a combination of both, sourced from diverse plant categories. These pesticides are derived from a range of plant components, such as roots, seeds, bark, leaves, flowers, fruits, cloves, rhizomes, and stems. Although a substantial number of bioactive compounds are documented, only a limited selection of plant species have undergone comprehensive assessments for their insecticidal properties (Isman, 2006). Among these, only four botanical products – azadirachtin, pyrethrins, rotenones, and essential oils – have successfully made their way into the market. The presence and quantity of the desired bioactive ingredients within the plant part determine the choice of plant part for making botanical pesticides.

Several plant families, including Myrtaceae, Zingiberaceae, Piperaceae, Liliaceae, Sapotaceae, Lauraceae, Lamiaceae, Rutaceae, Asteraceae, Apiaceae, Poaceae, Cupressaceae, Apocynaceae, Solanaceae, Caesalpinaceae have been identified as sources of plants containing varying bioactive compounds with efficacy against significant agricultural insect pests. These plant parts are usually subjected to drying and grinding, creating a finely powdered form for the production of botanical insecticides. The specific molecules of interest are then carefully extracted from these powders using different organic solvents. The resulting extracts are concentrated, prepared, and later tested in labs, under controlled conditions, or in the field for effectiveness.

Plants possess secondary substances that function as feeding deterrents, toxins, and repellents, serving as defenses against insect herbivores. Prior to the 1940s, these natural chemicals were commonly employed to safeguard crops, until the introduction of organochlorines. Among the various classes of commercial botanical insecticides, pyrethrins hold the highest economic significance. These active agents are primarily sourced from *Chrysanthemum cinerariaefolium* flowers and consist of a group of structurally related esters. The most prominent and insecticidal ones fall under the type I pyrethrins category (Schleier and Peterson, 2011). Pyrethrins induce heightened activity and convulsions through their "knock-down" effects. These compounds impact insect neuron membranes, triggering a neurotoxic response that activates sodium (Na^+) channels, resulting in excitation and heightened activity (Davies *et al*., 2007). However, pyrethrins are susceptible to degradation, particularly under UV light. Field studies indicate a half-life of approximately 2 hours, severely limiting their practicality for agricultural pest management (Fantke *et al*., 2014). Despite this vulnerability, pyrethrins remain the most extensively employed botanical insecticides globally and continue to be favored for household insect control purposes.

The roots (rhizomes) of tropical legumes generate a range of isoflavones, among them being rotenones. These highly potent secondary chemicals substantially suppress insect appetite, leading to their demise within a short span of hours or days. Rotenones, which are present in more than 67 species of the Fabaceae family, serve as a non-systemic insecticide with broad-spectrum effectiveness against aphids, thrips, and sap-sucking insects (Xu and Huang, 2001). Unlike pyrethrins, rotenone acts as a mitochondrial toxin, impeding ATP production. Its mode of action involves acting as a stomach poison, necessitating ingestion to take effect. Rotenones exhibit a persistence of 3-4 days upon exposure to air and sunlight, rendering them more enduring compared to pyrethrins (Yang *et al*., 2008). Another noteworthy group of plant-derived secondary compounds is azadirachtin, categorized as a limonoid. As reported by Mondal and Mondal (2012), it boasts a wide-ranging activity spectrum and intricate molecular complexity, effectively targeting around 550 insect species, primarily from orders such as Lepidoptera, Orthoptera, Siphonaptera, Diptera, Dictyoptera, Coleoptera, Thysanoptera, Heteroptera, Homoptera, and Isoptera. Azadirachtin functions as a systemic toxin and a molting inhibitor. Upon exposure, it promptly diminishes hunger and can lead to challenges in egg-laying, infertility, and the suppression of enzyme and chitin synthesis in insects. Furthermore, it can cause delays or disruptions in post-embryonic development (Liu and Liu, 2006).

How botanical pesticides works?

Botanical insecticides are sourced from dried and grounded plant materials, plant extracts, or isolated plant chemicals, and are harnessed for the management of insect pests (Isman, 2008). These insecticides capitalize on plant’s secondary metabolites encompassing non-protein amino acids, glucosinolates, steroids, quinones, phenols, alkaloids, flavonoids, glycosides, terpenoids, and tannins, which confer protective effects against insect pests. The historical use of botanicals traces back to ancient times, with pyrethrum's application as far back as 400 BC. Nicotine, the inaugural botanical insecticide, dates to the 17^{th} century, succeeded by rotenone's introduction in the mid-1800s, and subsequently, sabadilla and other botanical counterparts. Globally, farmers have employed plants or plant extracts containing potent defensive compounds to combat pests in both field and storage godowns.

Botanical insecticides adopt diverse mechanisms, including functioning as deterrents that thwart pests from locating food sources, acting as feeding inhibitors primarily due to terpenes, growth regulators that hinder insect development and disrupt metamorphosis, insecticidal agents leading to death upon contact or ingestion, and repellents generating unpleasant smells or irritations to repel insects (e.g., garlic and hot peppers). The presence of multiple active compounds in plant extracts makes it tougher for insects to develop resistance compared to synthetic insecticides, which often rely on a solitary active compound and mode of action (Hawkins *et al*., 2018). Botanical insecticides, on the other hand, are natural, exhibit swift action, and degrade rapidly, resulting in reduced environmental pollution. They also demonstrate low toxicity and selectivity to livestock and natural predators (with a few exceptions), and minimal risk to mammals. Additionally, botanical insecticides, particularly those sourced from locally cultivated plants, prove to be cost-effective and convenient to apply, offering advantages over their synthetic alternatives (Lengai *et al*., 2020).

5.2.1 Essential oils (EOs) as Botanical Insecticides:

EOs from aromatic plants are being used as insecticides more and more by organic growers and eco-conscious consumers. EOs offers a diverse array of effects on insect such as antifeedent activity, repellency, growth and oviposition inhibitors, ovicidal and growth-limiting effects. In addition to these they have acute contact and fumigant toxicity towards insects (Abdelgaleil *et al*., 2009). EOs lead to insect mortality by impeding acetylcholinesterase (AChE) activity in the nervous system of insects (Houghton *et al*., 2006). Owing to their pronounced volatility and lipophilic characteristics, essential oils exhibit potent toxicity to insects and rapidly permeate their bodies, disrupting physiological functions (Negahban *et al*., 2007).

The notable volatility of EOs also renders them effective when utilized as fumigants and gaseous agents against insects that infest stored products. They showcase intriguing larvicidal impacts on larvae like *Lymantria dispar* (Moretti *et al*., 2000), as well as toxic and repellent properties against ants, cockroaches, bedbugs, flies, head lice, and moths, in addition to being toxic to termites. As an illustration, *Mentha piperita* (peppermint) oil repels ants, moths, flies, and lice, while effectively managing *Tribolium castaneum* and *Callosobruchus maculatus* (Kordali *et al*., 2005). Larvicidal efficacy against *Aedes aegypti* and *Culex quinquefasciatus* mosquito larvae is demonstrated by oil from *Trachyspermum* species (Tripathi *et al*., 2000). The bio-active component, nepetalactone, found in *Nepeta cataria* (Catnip) EO, exhibits remarkable repellent action against bees, mosquitoes, and other flying insects, even surpassing the effectiveness of DEET. EOs originating from rhizomes of *Zingiber officinale* and *Piper cubeba* berries showcase insecticidal and antifeedant properties against *Sitophilus oryzae* and *Tribolium castaneum* (Chaubey, 2012a). *Tagetes* species derived EO exhibits insecticidal properties against *Triatoma infestans* and *Ceratitis capitata*. Moreover, essential oil from *Melaleuca alternifolia* exhibits fumigant action against *Sitophilus zeamais* (Min *et al*., 2016).

Eucalyptus, rosemary, mint, and oregano, mint oil are considered acceptable for treating surfaces or using in fumigation for cockroach control. Adults of *Acanthoscelides obtectus* is killed by the oils of *Eucalyptus globulus*, *Lavandula hybrida*, and *Rosmarinus officinalis* (Papachristos *et al*., 2004). Furthermore, essential oil derived from Tagetes minuta is toxic to Cochliomyia macellaria (Calliphoridae) and has acaricidal and repelling properties. (Chaaban *et al*., 2017). Linalool, another constituent found in basil oil, exerts toxic influence on bruchids and other storage pests, rendering it valuable for combating pests in stored grains or food items. EO of *Juniperus procera* has demonstrated notable repellent properties towards the malarial vector *Anopheles arabiensis*, implying its potential to mitigate mosquito bites and lower the risk of malaria transmission. Eucalyptus species-derived EOs, such as *Eucalyptus cinerea*, *Eucalyptus viminalis*, and *Eucalyptus saligna*, exhibit fumigant and repellent action against permethrin-resistant head lice (Toloza *et al*., 2006). These oils comprise various compounds, including citronellal, citronellol, p-cymene, eucamalol, 1, 8-cineole, citronellyl acetate, α-pinene, limonene, and linalool, contributing to the toxic and anti-feedant effects of eucalyptus oil. Eucalyptus oils enriched with cineole have proven effective against the varroa mite, a significant honey bee parasite, as well as against *Tetranychus urticae* and *Phytoseiulus persimilis*, pests that impact plants (El-Zemity *et al*., 2006).

5.3 Insecticidal Activities:

Tagetes minuta, *A. indica*, *C. cinerariaefolium*, *A. sativum*, *Mirabilis jalapa*, *Datura metel*, *L. camara*, and *R. speciosa* are a few examples of botanical insecticides that have been successfully used to manage a variety of pests that often attack *Phaseolus vulgaris* L., or common beans. Thrips and aphids, armyworms, grasshoppers, bollworms, cabbage loopers, caterpillars, bruchids, and pink stem borers are some of the pests that infest common bean (Karani *et al*., 2017). Extracts from *Carica papaya* L. and *T. minuta* have demonstrated significant success in reducing aphid populations and curtailing leaf damage. The robust outcomes of these extracts may stem from their diverse array of insecticidal constituents (Murovhi *et al*., 2020). For instance, *C. papaya* leaf extract contains a range of detrimental substances for sucking pests, like spotted bollworms, whiteflies and aphids. These include papain; a group of cysteine protease enzymes, flavonoids, alkaloids, terpenoids, and non-protein amino acids (Zobayer and Hasan, 2013). Phenylpropanoids, carotenoids, flavonoids, the phototoxin alphaterthieenyl, and thiophenes are all present in *T. minuta* leaf extracts and have all been shown to be successful in reducing insect infestations (Dunkel *et al*., 2010).

Azadirachtin, another botanical pesticide, operates through various mechanisms, including deterring feeding, influencing morphology, reducing fitness, suppressing reproduction, inhibiting growth, and even sterilizing pests (Zhang *et al*., 2018). In species like *D. melanogaster*, *S. frugiperda*, and *Callosobruchus maculatus*, azadirachtin has been observed to disrupt metamorphosis, leading to delayed pupation and diminished growth from larvae to pupae (Asaduzzaman *et al*., 2016). The higher amounts of azadirachtin and nimbin in neem bark extract make it more effective against lepidopteran pests than neem leaf extracts (Ahmad *et al*., 2018). Increased concentrations of neem oil have been linked to heightened mortality rates and physical impairments in pests' wings, legs, and scutellum (Zanuncio *et al*., 2016).

Against *Phenacoccus solenopsis* and *Aphis gossypi*, extracts of the leaves of *A. indica*, *Eucalyptus globulus* and *O. sanctum* and showed significant insecticidal potential in laboratory experiments (Singh *et al*., 2012). Furthermore, neem leaf extract has proven effective in reducing egg laying and adult survival rates of pests infesting stored grains and seeds (Ahmad *et al*., 2015). Plants are better able to fend off aphids when organic fertilisers are used in conjunction with neem leaf powder and boiler ash. Significant morphological abnormalities and delayed adult development in *D. melanogaster* have been linked to azadirachtin exposure during the pupal stage. In addition, azadirachtin exhibits potent antifeedant effects on *Galleria mellonella*, *Drosophila melanogaster* and *Plutella xylostella*. (Kilani-Morakchi *et al*., 2017) and also been reported to have sublethal effects on mating and post-mating behavior of *D. melanogaster* (Aribi *et al*., 2017) and reduces fecundity in this species (Abedi *et al*., 2013). These effects are attributed to the disruption of pathways leading to synthesis of 20-hydroxyecdysone and juvenile hormone, causing incomplete development of larvae, sterile eggs, and decreased reproductive capacity. Azadirachtin has been shown to cause 100% mortality in tobacco whitefly, *B. tabaci* after 72 hours of oral ingestion. In laboratory trials, 10% turmeric dust caused 80% mortality in pests such as *Amrasca devastans*, *Dysdercus cingulatus*, *Urentius hystricellus*, *Aphis gossypii*, *Earias vittella*, *Cnaphalocrosis medinalis*, *Oxya nitidula*, *Oxycarenus hyalinipennis*, *Epilachna vigintioctopunctata*, *Coccidohystrix insolitus*, *Anomis flava*, *S. litura*, and *Tetranychus neocaledonicus* (Sankari and Narayanasamy, 2007).

Furthermore, palmarosa, turmeric, and clove plant oils have been reported to suppress feeding activity in *S. frugiperda* caterpillars in the early instar stages (Sousa *et al.*, 2018). EOs have been shown to serve as anti-feedants, repellents, and oviposition deterrents, as well as larvicides, ovicides, and insecticides, interfering with different metamorphological stages of insects (Sarma *et al.*, 2019). Turmeric leaf EO has been demonstrated to be effective against three important stored product beetles, *R. dominica*, *S. oryzae*, and *T. castaneum*, when used as a contact or fumigant (Tripathi *et al.*, 2001). EOs like eucalyptus and rosemary have repellent effects on various insect species, including vectors (Pavela *et al*., 2011) by acting as a neurotoxin, leading to hyperactivity, followed by rapid knockdown and immobilization (Enan, 2001).

The insect pests suffocate due to allicin, derived from garlic bulbs (*A. sativum*), causing toxic effects on their neurotransmitter receptors (Baidoo and Mochiah, 2016). *Tagetes* spp. ethanolic extracts within the range of 2.8-5.8 percent (w/w) were effective in preventing the development and expansion of *S. frugiperda* (Tavares *et al.*, 2009). *E. globulus* leaf powder showed insecticidal activity against *Prostephanus trunatus*, as reported by Mukangas *et al*. (2010). Acting as a respiratory toxin, *Dalbergia saxatilis* leaf powder provided protection against the cowpea bruchid, *C. maculatus* (Okwute *et al*., 2009). *Piper guineense*, *Piper longum*, and *Piper retrofractum* extracts displayed a success rate of 96-100% in killing *Culex maculatus*, *Zonocerus variegatus*, and mosquito larvae within 48 hours (Dyer and Richard Dodson, 2004). *S. litura* fourth instar larvae exposed to *O. sanctum* oil (1000 ppm) exhibited a mortality rate of 13.33% (Baskaran *et al*., 2012). Additionally, clove oil resulted in the second-highest mortality rate (93.33%), following saunf and khas oil (100%). Both the rhizome and aerial components of the plant yielded extracts that demonstrated dosage mortality activity towards adult of *T. castaneum* (Abida *et al*., 2010). Treatments with onion (*Allium cepa*) or ginger (*Zingiber officinale*) significantly reduced populations of the tomato fruit worm (*Helicoverpa zea*) by 70-80%. Shah *et al*. (2013) found that extracts from *Curcuma longa*, *Ferula asafoetida* and *A. sativum* resulted in a substantial reduction in larval and pupal population of *H. armigera*.

5.4 Botanicals in India:

With India's extensive historical use of neem for various medicinal uses and safeguarding stored products, it's reasonable to infer that botanical pesticides are a standard component for Indian farmers. The country also boasts the highest count of organic producers (approximately 650,000) (Willer and Lernoud, 2015) and a significant volume of research on plant-based insecticides. As of 2012, the Ministry of Agriculture has granted licenses for nine botanical insecticides (Bambawale and Bhagat, 2012). The following plant extracts (together with the relevant active components) have also been authorised and are marketed, in addition to garlic and neem: *Milletia pinnata*, *Pongamia glabra* (karanjin, a furanoflavonol); *Annona squamosa* (squamocin and related acetogenins); *Apocynum venetum* (cymarin and/or related cardenolides); *Tripterygium wilfordii* (wilfordine and related diterpenoid epoxides); *Cymbopogon* spp. (monoterpenes, particularly citronellal and citral); *Eucalyptus globulus* (1, 8-cineole and other monoterpenes).

5.5 New Generation of Botanical Insecticides: Issues and Perspectives:

Plant-based and synthetic pesticides compete fiercely for market domination, with the former being less prevalent. Moreover, the field performance of plant-based pesticides relies significantly on current environmental and climatic conditions due to their rapid degradation. It is clear that there are issues with contamination and preparation potency, loss of pesticide effectiveness, and shelf life. Standardizing dosages for botanical pesticides might be challenging due to factors such as varying growth habitats, varietal variation, harvesting time, extraction method, and storage conditions. The intricate task of formulating botanical pesticides arises from the presence of multiple bioactive components in a single plant species, each possessing distinct chemical attributes.

The industrialization of plant-based pesticides encounters notable hurdles, encompassing: (1) the scarcity of botanical raw materials; (2) insufficient standardization and quality control of essential active ingredients; and (3) regulatory approval difficulties, involving costly toxicological assessments of botanical pesticides (Isman and Paluch, 2011). Botanical pesticides are safer than synthetic ones, but their uses in agriculture are regulated in much the same way. This is especially true in developing nations. Stringent environmental, toxicological, and registration evaluations are mandatory due to regulatory constraints, creating bottlenecks for these products.

5.6 Conclusion:

In economically disadvantaged nations, the utilization of botanical pesticides holds significant importance. While botanical insecticides might display reduced efficacy compared to synthetic counterparts, they remain a practical option, especially when integrated with Integrated Pest Management (IPM). This is particularly pertinent in regions where farmers lack access to commercial pesticides or can only afford a limited range of synthetic options. It is important to recognise and share information about the risks associated with using natural pesticides, such as their questionable efficacy and possible negative effects on human health and the environment. To strike a balance between safeguarding crops and mitigating the drawbacks of synthetic insecticides, plant-derived natural insecticides are embraced as a prime alternative to traditional pesticides. The realm of botanical insecticides encompasses diverse compounds and modes of action, influencing insects in various ways. Consequently, in more affluent nations, organic crop cultivators opt for these botanical insecticides over their synthetic counterparts.

Efforts are being directed towards promoting the adoption of botanical pesticides, along with ongoing research to discover new sources of botanical insecticides. Due to the large volume necessary for plant-based pesticide manufacture, active cultivation of plant sources should be performed to ensure a consistent supply of raw materials for industrial usage.

Overcoming formulation challenges, refining active ingredients, determining optimal application rates, enhancing storage stability, and addressing susceptibility to UV light can potentially aid the commercialization of botanical pesticides. For the successful entry of botanical pesticides into the market, collaboration among researchers, investors, manufacturers, marketers, and farmers is imperative. To substantiate the sustained benefits that warrant the integration of botanical pesticides, concerted efforts are essential. Given global concerns about environmental safety, government agencies must intensify their initiatives to educate farmers and manufacturers about the merits of transitioning to botanical pesticides as part of a sustainable pest management strategy.

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6. Biological Control of Insect Pests

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Abstract:

Sustainable agriculture is certainly one of the most important challenges at present, considering both human population demography and evidence showing that crop productivity based on chemical control is plateauing. While the environmental and health threats of conventional agriculture are increasing, ecological research is offering promising solutions for crop protection against herbivore pests. Growers and green industry professionals are searching for alternative pest management tactics to satisfy consumer demands and the desire for sustainability and operational flexibility. Many are considering biological control. Biological control is the use of non-chemical and environment friendly methods of controlling insect pests and diseases by the action of natural control agents. The benefits of biological control include reduced reliance on pesticides, decreased potential for development of pesticide resistance, flexibility in usage of personal protective equipment, shorter (or no) restricted entry intervals. Government and manufacturing organizations are developing regulations to assure the safe and appropriate use of biocontrol. Protection of biodiversity and high benefit to cost ratio are obvious reasons to promote the use of biocontrol platforms.

Keywords:

Biocontrol, biocontrol agents, chemical control, environment friendly, biodiversity.

6.1 Introduction:

Indian agriculture sector contributes tremendously towards national GDP their by nation's economy. India produces almost all the crops starting from food grains, horticulture crops and commercial crops (Vanitha *et al*., 2013; APEDA 2020). Even though, there are a number of methods available to control the damage, usage of chemical pesticides is being followed in a large scale especially during post green revolution years. But the unscientific and indiscriminate use of chemical pesticides brought into various problems like residues in products, harmful effects on human and animals along with environmental pollution. On the other hand, various reports from different researchers that, most of the insect pests developed resistance against major insecticides.Resurgence of the pests also being notices in many parts of the country. This has raised a serious concern among researchers and growers to look into alternative/corrective measures of pest control to achieve sustainable crop protection, production and environmental safety. One such option is the biological control which eventually attained global preference over synthetic pesticides for effective and eco-friendly management of insect pests. Here living organisms and their products are used to maintain pest populations below economic threshold levels (ETL) which also protect natural enemies (Altieri *et al*., 2005; Mahr *et al*., 2008). Significant research and development has taken up during past few decades for biological control of insect pests. Over the past 50 years, biological control remains as one of the component of IPM and showing a steady but promising growth in IPM (Orr, 2009).

Biological control is an environmentally sound and effective means of reducing or mitigating pests and pest effects through the use of natural enemies. It relies on predation, parasitism, herbivory, or other natural mechanisms, but typically also involves an active human management role (Brodeur *et al*., 2013). According to S. H. Dreistadt, 2007, Biological control is the beneficial action of predators, parasites, pathogens, and competitors in controlling pests and their damage. Biocontrol provided by these living organisms (collectively called natural enemies) is especially important for reducing the numbers of pest insects and mites. Biological control has been actively practiced for many years and the history of biocontrol, its failures and successes, has been extensively reviewed. Interest in biological control has increased over recent decades for many reasons (Bailey *et al*., 2009). First, a greater appreciation for environmental stewardship among regulators, growers, and the public has promoted development of more sustainable farming practices. Second, a number of arthropod pests have developed resistance to one or more pesticides leaving growers to search for alternative management strategies (Mc Caffery, 1998). Finally, consumers increasingly demand products that are grown in a sustainable manner and are free of insecticide residue (Dabbert *et al*., 2004). Despite this, growers have been slow to adopt biological control as part of their pest management program. The primary factors affecting adoption of biological control are efficacy, predictability, and cost (Van Driesche and Heinz, 2004).

Basically there are three types of biological control strategies applied in pests control programs. These are Importation (sometimes called classical biological control), Augmentation and Conservation. Classical biocontrol is defined as the intentional introduction of an exotic (non-native), usually co-evolved biological control agent for permanent establishment and long-term pest control (Van Driesche, 2008). On the other hand, augmentation involves the supplemental release of natural enemies, boosting the naturally occurring population. Relatively few natural enemies may be released at a critical time of the season (inoculative release) or millions may be released (inundative release). An example of inoculative release occurs in greenhouse production of several crops. The conservation of existing natural enemies in an environment is the third method of biological pest control. Natural enemies are already adapted to the habitat and to the target pest, and their conservation can be simple and cost-effective, through vegetation manipulation, Natural enemies of insect pests, (biological control agents) include the following; predators, parasitoids, and pathogens. Predators are mainly free-living species that directly consume a large number of preys during their whole lifetime. A parasite is an organism that lives and feeds in or on a larger host.

Insect parasites (more precisely called parasitoids) are smaller than their host and develop inside, or attach to the outside, of the host's body (S. H. Dreistadt, 2007). Pathogenic micro-organisms include bacteria, fungi, and viruses. They kill or debilitate their host and are relatively host-specific.

6.2 Need for Biological Pest Control in India:

There is very much essential to meet the growing population of the country and their food demands. Beyond good production and productivity of agriculture and horticulture produce, the farmers often facing number of problems including high application of inputs especially chemical fertilizers or pesticides and nutrients to get good yield and control of various insect pest and diseases. This has lead to the high cost of cultivation and investment which will reflect yield and monitory returns. On the other hand, the chemical pesticides and fertilizers have created environmental pollution and also affect human and animal life. This has led to considerable changes in attitude of farmers towards use of pesticides and switching over to alternate and eco-friendly approach. One such option is biological control where number of agents integrated into IPM practice for successful management of pests. Here no microorganism or beneficial insects will deliberately introduced or manipulated for biological control. The potential agents will be tested repeatedly under controlled conditions against a target pest followed by mass production and release for commercial purpose (Hodek *et al*., 2012).

There are three general approaches to biological control:

As mentioned above in introduction, there are 3 basics strategies in biological control of pests, these are;

6.2.1 Classical Biological Control (Importation):

Classical biological control is the importation of pest natural enemies from other countries, to a new locale where they do not occur naturally. It is the international introduction of an exotic, usually co-evolved, biological control agent for permanent establishment and long term pest control (Pickrell, 2004). The goal of classical biological control is to find useful natural enemies, introduce them into the area of the target pest, and permanently establish them so that they will provide continuing pest control with little or no additional human intervention. The search for natural enemies in other countries is often referred to as foreign exploration. The process of importation involves; determining the origin of the introduced pest, collecting appropriate natural enemies associated with the pest or closely related species. Then selected natural enemies are passed, through a rigorous assessment, testing and quarantine process, to ensure that they will work and that no unwanted organisms are introduced. Mass production and release of selected natural enemies.

Follow-up studies are conducted to determine if the natural enemy becomes successfully established at the site of release, and to assess the long-term benefit of its presence. The cottony cushion scale (*Icerya purchasi* Maskell) program in California over the period 1877- 1879 was the first scientifically and institutionally backed biological control program. The importation and release of two natural enemies, the vedalia beetle (*Rodolia cardinalis*

[Mulsant]) and a parasitic fly (*Cryptochaetum iceryae* [Williston]) from Australia for cottony cushion scale control in California (M.S. Hoddle, 2003). In recent years, classical biological control has come under increasing scrutiny for its non target effects (Cory and Myers, 2000; Hawkins and Marino, 1997; Howarth, 1991). However, there are many examples of successful biological control (Bellows, 2001), and the need for biological control is increasing (Cory and Myers, 2000). Lastly, Classical biological control is a powerful tool for suppression of invasive plants and insects in natural ecosystems. It will play an increasingly important part in ecological restoration because; it provides a means to permanently suppress invaders over large landscapes without long-term resource commitments and hence is sustainable. As such, it merits use against many invasive plants and insects that are environmental pests in sensitive landscapes (Morin *et al*., 2009).

6.2.2 Augmentation Biological Control:

Augmentation is the periodic release of a natural enemy that does not occur naturally in sufficient numbers to keep a pest below damaging levels. It's also defined as the release of additional numbers of a natural enemy when too few are present to control a pest effectively (van Lenteren, 2000). The practice of augmentation is based on the knowledge or assumption that in some situations there are not adequate numbers or species of natural enemies to provide optimal biological control, but that the numbers can be increased by releases. This relies on an ability to mass-produce large numbers of the natural enemy in a laboratory or by companies to produce and sell them. There are two general approaches of augmentation: inundative releases and inoculative releases.

A. Inundative Releases:

Inundation involves releasing large numbers of natural enemies for immediate reduction of a damaging or near damaging pest population. It is a corrective measure; the expected outcome is immediate pest control. The inundative approach is achieved by flooding the crop with multiple releases of insectary-reared natural enemies. The released insects control pests present at the time, but there is little expectation that later generations will persist at sufficient levels to provide control. In practice, releases are often repeated if pest populations were not all present in a susceptible stage during the previous application, if new pests disperse into the crop, or if the crop is long lived, increasing the length of time it could become infested (Eilenberg *et al*., 2001). Moreover, Inundative release of natural enemies is undertaken; causing effects similar to the use of conventional insecticides, as there is a knockdown effect of the target host population. Therefore, it may be used in the field and in greenhouse as seasonal release (Cohen 2004, Schneider 2009). However, because of the nature of natural enemy activity, and the cost of purchasing them, this approach using predaceous and parasitic insects is recommended only in certain situations, such as the mass release of the egg parasite *Trichogramma* for controlling the eggs of various types of moths.

B. Inoculative Releases:

Inoculation on the other hand; involves releasing small numbers of natural enemies at prescribed intervals throughout the pest period, starting when the pest population is very low. The natural enemies are expected to reproduce themselves to provide more long-term control. However, the expected outcome of inoculative releases is to keep the pest at low numbers, never allowing it to approach an economic injury level; therefore, it is more of a preventive measure. The separation of inoculation from inundation is clear. A release with the expectation that the released organism will control the target after multiplication is inoculation. Examples of this are the releases of *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) and other natural enemies, now commonly practiced in glasshouses (Eilenberg *et al*., 2000; van Lenteren, 2000). The number of insects released is insufficient to control the pest insects, and success depends on the ability of the released organisms to multiply and reduce the target population.

6.2.3 Conservation Biological Control:

Conservation biological control is defined as modification of the environment or existing practices to protect and enhance specific natural enemies of other organisms to reduce the effect of pests. Habitat manipulation often involves increasing the species diversity and structural complexity of agro ecosystems. Habitat manipulation approaches provide natural enemies with resources such as nectar, pollen, physical refugia, alternative prey and alternative hosts and operate to reduce pest densities via an enhancement of natural enemies. However, although conservation biological control often increases natural enemy abundance, reduced pest abundance or increased yield has rarely been demonstrated (Johnson *et al*., 2008). For example, flowering strips and other shelter habitats, as conservation biological control tactics, increase predation, parasitism, or yield in some cases but not others (Pfiffner and Wyss, 2004 and Griffiths *et al*., 2008).

In addition to natural enemies, conservation biological control tactics, such as habitat manipulation, attract and sustain a diverse suite of herbivores, detritivores, and plant provided foods (Landis *et al.*, 2000; Frank and Shrewsbury, 2004). Research has been done on myriad arthropod pests, including species with high levels of insecticide resistance such as *Chilo suppressalis* (Lepidoptera: Crambidae) and *Helicoverpa armigera* -Lepidoptera: Noctuidae (Cory S. Straub *et al.*, 2007). As an example of conservation biological control, alternative habitats for natural enemies are provided, in the form of ‘beetlebanks’ in Britain or ‘sown seed strips’ in Switzerland in cereal crops. These practices are highly successful and are among the few documented uptakes of a biological control option in temperate open-field arable agriculture (Landis *et al*., 2000).

A. Biological Control Agents:

Most of the plant protection measures in India are depends exclusively on chemical pesticides. The farmers are using pesticides making it a calendar based application. This has become a common practice over the years by growers. Unknowingly they are destroying natural flora and fauna along with killing beneficial insects like predators, parasitoids and bees. Therefore it is absolutely necessary for the farmers to use biological control agents to conserve these beneficial insects along with safeguarding environment (Altieri *et al*., 2005; Mahr *et al.*, 2008; Halder *et al.*, 2011). During past few decades, a steady progress has been made in India towards biological control of insect pests. But, this needs to be aggravated in terms of searching more and more natural enemies, and microbial bio control agents for efficient management of insect pests.

- **Predators:** Predator insects are the beneficial insects which directly kill and feed on pests. Common predatory insects include lacewings, ladybird beetles, carabid beetles, staphylinid (rover) beetle, syrphid (hover) flies, minute pirate bugs, nabid bugs, big-eyed bugs, spiders and preying mantids. Ladybird beetles are recognized for their predatory behavior on many pests. Adult and larvae of ladybird beetle feed on a number of small, soft-bodied insects, their eggs and larvae. Most of the predators are not host specific. They can feed on a number of pests including plant pests and insects eating on organic matter also. Predators are generally have chewing and sucking type of mouth parts and some types they have both the types (Sampaio *et al*., 2010). Some of the insect orders have exclusively predatory insects. Example: The order Odonata has dragon flies, where aquatic nymphs are predatory, and breath through gills. Whereas adults are excellent fliers captures their prey during flight from crop fields. Another order is Mantodea which have praying mantids. They are the excellent hunters of their prey by hiding on leaves and plant surface to confuse their prey. They have strong modified front legs to capture their prey. Similarly order Neuroptera have lacewings and ant-lions where, all the larvae are predators and adults feed on pollen and nectar (Sampaio *et al*., 2010). Order Diptera have rover flies which have similar mechanism of dragon flies to catch their prey. Other orders is Coleoptera (Coccinellids) having lady bird beetles which are the excellent predators. Many of the mite species belong to phytoseidae also reported to have predatory action. They are the important natural enemies of other mites
- **Parasitoids:** Parasitoids are the organisms which live and feed inside or on the host. The parasites can develop inside or outside of an insect's body. Only immature stage of the parasites feed on insect host. Adult females of certain parasites feed on and their hosts providing an easily available source of biological control (Sanda and Sunusi, 2014). Based on the stage of prey that a parasite attacks, they are categorized into egg parasitoids which have whole development within the egg of other insect. Egg-larval parasitoid is the one that has oviposition within egg of the host, but its development completed in the insects larvae. Other parasitoids are larval, pupal and larvae-pupae. In some cases, adult stage of the insects also used as host by the parasitoid (Sampaio *et al*., 2010). When the parasitoid develops on the host, it is called ectoparasitoid and when it develops inside it is called endoparasitoid. Most of the parasitic insects belong to order Diptera (flies) or Hymenoptera (Wasps). Parasitic wasps occur in three dozen Hymenoptera families. Example: Aphidiinae (subfamily of Braconidae) attack aphids that are pests in most of the crops. Other family is Trichogrammatidae, here pasitization is observed on eggs. Aphilinidae, Encyrtidae, Eulophidae and Ichneumonidae are the other families' parasites on insect pests (Flint and Dreistadt, 1998).
- **Microbial Biocontrol Agents:** Just like plant pathogens, these are microbial agents belongs to fungi, bacteria, protozoa, virus, actinomycetes and nematodes which attack insect pests and kill them. Innudative application can be followed by formulating insect-pathogenic fungi (*Metarhizium*, *Beauveria*, *Paecilomyces*), insect-pathogenic bacteria (*Bacillus thuringiensis*), entamopathogenic nematodes (*Heterorhabditis* and *Steinernema*) and viruses (nuclear polyhedrosis virus-NPV and granulosis viruses (GV) (Flint and Dreistadt, 1998). The fungal biocontrol agents belong to 12 classes within six phyla of the major groups like Laboulbeniales, Pyrenomycetes, Hyphomycetes and Zygomycetes. Many of the promising biocontrol agents have been ommercialized globally. They have been proven their efficacy on insect species belonging to Lepidoptera, Homoptera, Coleoptera, Orthoptera and Mites. Majority of the bacterial biological control agents are *Bacillus thuringiensis* based *Bt* formulations. For example

in cabbage they are being used in two formulations like Btkurstaki and Btaizawai as control of diamond back both (DBM) and other defoliating lepidopteran insects (Shelton *et al*., 2007). These formulations are highly specific and very effective against target pests without any impact on natural enemies. Most of the formulations are spore-crystal mixtures having toxins (Btk-Cry1Aa, Cry 1Ab, Cry 1Ac. Cry 2a2A and Cry 2B; Bta;Cry 1Aa, Cry 1Ab, CryIC, Cry ID and Cry 2B toxins) (Heckel *et al*., 2004; Grzywacz *et al*., 2010). Among the fungal biocontrol agenst, *Beauveria bassiana*, *Metarhizium anisopliae*, *Nomuraea rileyi*, *Lecanicillium* spp., gained much more attention during the past 30-50 years. There are more than 300 commercial products available in world market (Faria and Write, 2007).

6.3 Conclusion:

Biological control of pests is the use of pathogens, predators and parasitoids to kill pests by reducing their populations or eliminating them completely. Biological control is generally regarded as most effective and sustainable way of pest management. Conservation of natural enemies, predators, parasitoids and microbial biocontrol agents can sustain the pest management alternative to chemical pesticides. Though biological control will not control all the insects at a time, it should be an integrative component of integrated pest management.

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7. Quorum Sensing, The Signalling Pathway in Bacteria

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Abstract:

Quorum sensing is term given to the cell-to-cell communication that occurs between the bacterial population. It occurs through various diffusible chemical signals that effect the gene regulation when the bacterial cell density is high. Quorum sensing changes the metabolic and behavioral activities of a community. It is used by both gram negative and gram-negative bacteria and involves the production of extracellular signalling molecule called autoinducers. Quorum sensing is utilized by the bacteria for various activities such as sporulation, virulence, biofilm production, anti-biotic production etc. Among pathogenic bacteria Pseudomonas aeruginosa utilizes quorum sensing for regulating virulence factors. Quorum sensing is also being considered as a means to exploit for antimicrobial therapy to control bacterial infections. Gram negative uses N-acyl homoserine lactone as autoinducer, quorum sensing with the help of HSLs occurs in a cell density and growth dependent manner. Whereas, gram positive bacteria secrete processed peptied to be used as autoinducers. In this chater, we will discuss the basic mechanism of quorum sensing in gram negative and gram-positive bacteria with appropriate examples. The biofilm production by pathogenic bacteria is often connected with quorum sensing. It enables the bacteria to up regulate or down regulate the secretion of extracellular polymeric substances to increase their competitive ability against different strains present withing the biofilm or against other species.

Keywords:

Quorum sensing, bacteria, cell to cell commuication, biofilm production, autoinducers.

7.1 Introduction:

Bacteria exist as individual cells. They have the unique ability to undergo intercellular communications with other bacterial cells, which proves that they can coordinate with each other. Because of these capabilities bacteria can behave collectively as a group and perform important functions such as migration to a favourable environment, sporulation, antibiotic production and biofilm production etc. (Kievit and Iglewski, 2000).

This phenomenon of coordinated behaviour is known as Quorum sensing. It is known as the regulation of gene expression in response to changes in cell-population density. It requires the use of chemicals signalling pathway via molecules called autoindiucers.

The concentration of autoinducers increase with increase in cell density (Miller and Bassler, 2001). When a single bacterium releases autoinducers (AIs) into the environment, their concentration is too low to be detected. The detection of a minimal threshold concentration of the chemical leads to an alteration in gene expression of another bacteria in the vicinity. When sufficient bacteria are present, autoinducer concentrations reach a threshold level that allows the bacteria to sense a critical cell mass and, in response, to activate or repress target genes. Most of the bacteria identified that utilize quorum-sensing systems are associated in some way with plants or animals. Quorum sensing, is used by both Gram-negative and Gram positive bacteria to regulate a variety of physiological functions. Studies show that quorum sensing maintains both intra- and inter-species cell–cell communication, and it plays a major role in enabling bacteria to perform complex community functions. Bacteria are also known to regulate their phenotype with the help of various components of quorum sensing.

Gram-positive and Gram-negative bacteria use quorum sensing communication for an array of physiological activities such as symbiosis, virulence, competence, conjugation, antibiotic production, motility, sporulation, and biofilm formation.

The autoinducer used by gram-negative bacteria is acylated homoserine lactone and gram-positive use processed oligo peptides. this type of communications occurs at both inter and intra species level. The autoinducers produced by the bacteria function to elicit a specific response from the host. The nature of the chemicals signals and the mechanism with which it works differs in every organism but the essence remains the same i.e. to regulate coordiante gene expression of a larger group of bacteria and ultimately have an effect on the behaviour of the entire community.

7.2 Quorum Sensing in Gram Negative Bacteria:

Quorum sensing in gram negative bacteria occurs with the use of N-acyl homoserine lactones (NHL) as autoinducers or signalling molecules. These molecules have a tendency to bind to a transcriptional activator at high concentrat, which will thereby lead to the expression of the target genes. AHLs were discovered by with the help of biosensors. These biosensors, consisting of quorum sensing controlled promoter connected to a reporter such as lacZ or the lux operon, were used to screen spent culture supernatants. Biosensors also contain a functional R protien but are devoid of AHL synthase enzyme and hence, promote activity depending on the presence of exogenous AHL. Even though the R protiens are used extensively and are highly sensitive to AHL,but some problems do exist. R protiens are able to be responsive for a large number of AHL molecules, but only at high concentration of AHL molecules. Identified AHL molecules contains 4 to 14 carbon acyl sides chains and an oxo, a hydroxy or no substituion at the third carbon. Some gram-negative bacteria also contain alternate signalling molecules other than the AHLs. For example, R. solanacearum produces 3-hydroxypalmitic acid methyl ester in combination with AHLs as signalling molecules to regulate virulence among the population. (Flavier et al., 1997).

In Pseudomonas aeruginosa most common type of autoinducer produced is a 2-heptyl-3-hydroxy-4-quinolone. Along with this, a new form of autoinducer has been identified that is produced by the bacterium called as PQS (*Pseudomonas* quinolone signal) (Pesci et al., 1999).

Another molecule, butyrolactones have also been isolated from Pseudomonas aureofaciens vulture supernatants. A new family of diketopiperazines (DKPs) has been discovered in *P. aeruginosa, Pseudomonas fluorescens, Pseudomonas alcaligenes, Enterobacter agglomerans, and Citrobacter freundii* (Holden et al., 1999). Many of these molecules were capable of activating the the LuxR based biosensors, but the DKPs were found to affect negatively regulate the N-3 homoserine lactone mediated bioluminescence, which suggests that they might be competing with the LuxR binding (Prasad, 1995).

7.2.1 The LuxI/LuxR Quorum Sensing Systems:

The system of LuxI/LuxR quorum sensing has been used to control cell density dependent functions for over 30 species of gram-negative bacteria (Swift et al., 1999). This system utilizes HSL as autoinducer. It is synthesized on a luxi homologue and a luxR homologue as well, encoding for a transcriptional activator protien which is responsible for detection of the autoinducer (HSL) and lead to the expression of the output. R. solanacearum uses quorum sensing to control virulence of the plant cell and for the production of cell wall degrading enzymes. Its system is known as SolI/SolR system which is regulated by a LysR like regulator called the PhcA, which responds to an autoinducer (3-hydroxy-palmitic acid methyl ester). It is controlled by RpoS, which is stationary factor (Flavier et al., 1997). Quroum sensing can sometimes be responsiable for both bacterial as well as host signals. This is observed in Agrobacterium tumefaciens, a crown call causing bacterium. Here, the opine hormones secreted by the plant interacts with the bacterial protien called OccR and regulates the expression of Lux R homologue TraR (Winnas et al., 1999).

Bioluminescent qourum sensing system if the marine bacetrium *V. fischeri* is one of the most studied systems. Here the bacterium is known to be in a symbiotic relationship with a eukaryotic host. The host (squid) has a specialised light organ in which the pure culture of a strain of *V. fischeri* resides. In this particular type of association, the host provides the bacterium with a nutrient rich environment to live and the bacteria provides the host with light. The emission is directly related with the cell population density of the bacteria in the host organ, which is in turn controlled by quorum sensing. The bacterial culture inside the host organ reaches a population sensity of upto 1011 cells per ml (10^7) and produces and releases an autoinducer into the environment. This hormone gets trapped inside the light organ with the bacteria. This autoinducer molecule inside the light organ acts as signalling molecule. This accumulation of the hormone gives signal to the bacteria of being present inside the host and not outside in the water, as the light organ of the host is the only place where the hormone can be accumulated. When *V. fischeri* detects the presence of the autoinducer it leads to the emission of light (Engebrecht et al., 1983). There are various enzymes required for the production of light of these, the luciferase enzyme is encoded by luxCDABE which is an inherent part of a larger operon called the luxICDABE (Lee et al., 1993). LuxI and LuxR protiens constitute the quorum sensing system. The autoinducer synthase enzyme (LuxI) helps in the production of HSL, N-(3-oxohexanoyl)-homoserine lactone (Eberhard et al., 1983). Whereas, LuxR has two functions, first to bind with the autoinducer and second to activate trasncription of the luxICDABE operon. In situations where the population of the bacteria is not sufficient, a operon is transcribed at a low base level producing a low level of light. Kaplan ad Greenber in 1985 states that, the HSL autoinducer diffuses across the cell membrane therefore, equal concentration of HSL is present in the extracellualr and intercellular environment.

With the growth of the culture of *V. fischeri*, the concentration of the autoinducer also grows up to a threshold level of 1-10 µg/ml, which is required for detection and binding by the LuxR protien. Interaction of luxR with HSL reveals the LuxR DNA binding domain, which allows it to bind to the luxICDABE promoter and activate transcription, beacuase of this there is a substantial increase in the concentration of both autoinducer production and light emission. The LuxRHSL complex may also sometimes act negatively to regulate the expression of luxR. The negative feedback decreases luxICDABE expression.

7.2.3 Quorum Sensing in Gram Positive Bacteria:

Quorum sensing is an important phenomenon observed in many gram positive bacteria. The signalling molecules of gram positive bactria differ from those found in the gram negative bateria. Quourum sensing is used to perform various function in gram positive bacteria such as DNA uptake in B. subtilis, virulence in *S. aureus*, conjugation in *Enterococcus faecalis* and microcin production in bacteria such as *Lactobacillus sake* and *Carnobacterium piscicola*. Unlike gram negative bacteria which employs the usse of LuxI/LuxR signalling pathway and HSLs as signalling molecule gram positive bacteria use processed peptide signalling molecule through a ABC (ATP-binding cassette) exporter protien. The signal generated by the peptides is recognised by two component sensor kinase protien which will further interact with cytoplasmic protiens. This mechanism is called the phosohorelay cascade (Kleerebezem et al., 1997; Novik and Muir, 1999). Lazazerra and Grossman (1998) explained the QS mechanism as observed in *B. subtilis.* They proposed that the two processed peptide signals enables the bacteria to choose between becoming competent for foreign DNA uptake or to undergo sporulation. Research has not been able to understand the science behind the srection machinery for these two peptides. One of the two peptide ComX is known to activate the ComP/ComA system to allow the the bateria to transition towards a more transformable condition. Peptide CSF (commonly called competence and sporulation factor) is imported by an ABC transporter. Turgay et al (1998) reported that different concentration of the CSF will lead to different result such that, at high CSF concentration competence will be inhibited and sporulation favoured whereas, at low concentration of CSF competence development is favoured. To summarize we must understand that in gram positive bacteria, secreted peptides function as autoinducers which in high concentration are detected by two component sensor kinases. The interaction between the two initiates a series of phosphoryl events which results in phosphorylation of the regulator protein. This phosphorylation activates the regulator protien which allows it to bind to the DNA and alter the transcription of the target gene.

S. aureus is another example of the gram positive bacteria undergoing quorum sensing. Dunny and Leonard (1997) reported that the virulence of the bacteria depends on cell associated protiens like protien A, collagen and fibronectin-binding protien, proteases, alpha toxin etc. During infection, the attachment of the bacterium to the host is of utmost importance and is favoured by surface protiens such as collagen and fibronectin-binding protien along with protein A required for defence. When the concentration of the bacterium at the host surface reaches a certain level, the expression of these surface protiens is known to decrease giving way for the production of secreted protiens (Ji et al., 1997). The genetic basis for this depends on two pleiotropic regulatory loci called agr (accessory gene regulator (Morfeldt et al., 1988) and sar (staphylococcal accessory gene regulator). The agr locus consists of two divergently transcribed operons, RNAII and RNAIII).

The RNAII operon constitutes the agrBDCA genes which encode for signal transducer (AgrC) and resonse regulator (AgrA) and AgrB and AgrD, which together generate the signal molecule. The AgrC signal transducer is autophosphorylated in response to the signal molecule, this leads to phoosphorylation of the AgrA response regulator. AgrA helps in the transcription of RNAIII, which upregulatos the expression of various *S. aureus* protiens and positively regulates the agrBDCA locus. This locus leads to a rapid increase in the production and transport of octopeptide signal molecule. The second locus sar, produces the sar gene product (sarA) whose main function is to regulate DNA-binding protien to induce expression of both RNAII and RNAIII operons of the agr locus.

7.2.4 Evolution of Quorum Sensing in Bacterial Biofilms:

An important example of coordinated social behaviour in bacteria is the production of biofilms. This phenomenon involves the secretion of polymers used to envelope the communities of cells attached to the surface of the host. This polymer is secreted only when the bacterial population reaches a certain level. Nadell et al (2008) used individual based simulations to study the competitions between different strains of bacteria throughout evolution, which differ in their secretions of these biofilm producing polymers and quorum sensing phenotypes. It is known that polymer secretion is activated at high cell density which starts the biofilm formation. This is necessary as it allows the bacteria to provide a nutrient rich medium for the growth of its newer generation. It was unclear as to why quorum sensing is used again to stop the polymer secretions at high cell density. The researchers were able to establish that the reason for this termination lies in the fact that, once biofilm production has been stopped the resources can then me redirected towards growth of the bacteria, but this was only possible for a limited time frame. Therefore, it was theorized that the polymer secretion termination will evolve when it coincides with dispersal events. They suggested that the variation in quorum sensing can be attributed to the requirement of bacteria in chronic or acute biofilm infections. For example, *V. chlorae*, uses biofilm production to overcome production and then subsequently terminates it at high cell density and leads to disease which ultimately helps in the dispersal of the bacteria from the host.

7.3 Role of AHL in Biofilm Formation:

Biofilms are known to be aggregation of microorganisms which attach themselves to a solid surgace in a matrix of extracellular biopolymers. McLean et al (1997) reported that AHL or N-acyl-L-homoserine lactones play an important role in the biofilm production of many bacteria. They have been detected from many aquatic biofilms. They play asignificant role in the virulence of the bacteria. AHL negatively impacts the biosynthesis of extracellular polysaccharide (Koutsoudis et al., 2006). EPS is functionaly involved in the virulence of the bacteria. The function of the EPS inculde protecting the bacteria from the host defences, and aid in the formation of lesions by water-soaking and lead to wilting by blocking the free flow of water in the vascular system of the plant.

Psuedomonas syringae causes the brown spot in beans and is another pathogen which utilises the AHL dependent EPS production (Quinones et al., 2005). Other than the plant pathogenic bacteria, certain human bacterias also produce AHL-dependent biofims, which is commonaly observed in patients of cystic fibrosis, a genetic defect. Cystic fibrosis is a condition which regulates the transport of chloride ion in the chloride ion channel. A defect in cystic fibrosis gene leads to secretions of mucoid which leads to chronic bacterial infections in the lungs. *P. aeruginosa* forms a biofilm in the lungs of the patient in an AHL dependent process (Dickschat, 2010).

7.4 Conclusion:

Bacteria's ability to coordinate behavious at cell density has many advantages. Pathogenic microorganisms need to regulate virulence factors throughout the infection process, which helps in their pathogenicity. One of the most important aspect of pathogenic bacteria is to evade the defence of its host. As of now quorum sensing plays the most important role in helping the bacteria to overcome the defence responses of the host by timely expression of immuntiy related protiens. Quorum sensings allows the bacteria to multiply in number to an appropriate level and then develop the virulence factors, and put forward a coordinated and planned attack to overwhelm the host defences. There are a number of bacteria which make use of the complex system of quorum sensing, and for this precise humans have found ways to manioulate and exploit it for their own benefit. Strategies can be planned out to manipulate the quorum sensing and hample the virulence of the disease causing pathogen. Quorum sensing if used by human pathogenic bacteria can be utilised against it, by exploiting the signalling molecules such as AHL to control human infections. The discovery that *P. aeruginosa* uses quorum sensing to regulate biofilm production suggests that agents capable of blocking quorum sensing may also be useful for preventing biofilm formation. The recent production of AHLs in plants represents an exciting new approach to controlling crop diseases as well as to manipulating plant-microbe interactions for improved crop production in the future.

Bacteria in general, have optimized quorum sensing to regulate a number of activities and in every case, quorum sensing gives the bacteria capability to be communicate with each other and alter their genetic response to a stimuli. Bacteria have evolves in such a way to use quorum sensing in an interspecific as well as species specific manner. This ability of the bacteria provides it with extra benefit to be able to adapt to various environmental conditions, grow competetively and survive, using autoinducers. New antimicrobial strategies can be designed in the future, to manipulate quorum sensing mechanism of the bacteria for human benefit. The challenge faced by the clinicians in the future will be to understand the complex nature of autoinducer-based signalling and develop effective therapeutic startegies.

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8. Disesease of Cereal Crops and Their Management

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Abstract:

Famers all over the world growing cereals, loss their economic gains due to diseases caused by pathogens. The quality of the yields of cereals depends on crop management system and correct diagnosis of the disease at the right time. This chapter reviews all the major diseases causing economic loss in India and around the world. The symptoms of the disease are explained in a precise and simple manner for proper and immediate diagnosis. Fungal diseases in cereals cause up to 20-60 per cent crop loss. Factors which determine the occurrence of diseases are weather parameters, cultural practices such as growing season, monoculture practices, crop rotation, soil tillage etc. these diseases are known to decrease plant growth, reduce grain yield and quality. The diseases disease causing most damage among cereal crops include the likes of rusts, bunts, mildews etc. these may vary in intensity season after season depending on the availability of favorable conditions conducive for the growth of the pathogen.

Keywords:

Cereals, rusts, symptoms, epidemiology, control, fungicides

8.1 Wheat:

Wheat is one of the most important cereal crops, contributing about 30 per cent to our total food production. Wheat yields fluctuate over the years due to various biotic and abiotic stresses. Diseases caused by fungi are most important followed by bacterial and viral diseases.

A. Rusts:

Symptoms:

- **Yellow/Stripe rust (*Puccinia striiformis*):** The uredo pustules are small, oval, containing yellow to orange-yellow uredospore's, arranged end to end in narrow stripes on the leaves. Pustules are found on the leaf sheaths along with necks and glumes. The teliosori covered by epidermis are dull black in color and also arranged in long stripes chiefly on under surface of leaves, also on other green parts of the plants.

- **Brown/Leaf rust (*Puccinia triticina*):** The pustules are round to slightly elliptical, scattered or in clusters, contain masses of orange to orange brown uredospore's, primarily formed on the leaves and occasionally on the leaf sheaths, stalk and ears. As the plants mature, the uredosori are gradually replaced by teliosori. These are silvery black in color and covered by epidermis.
- **Black/Stem rust (*Puccinia graminis tritici*):** The uredo pustules are large, scattered, may coalesce, elongated, dark reddish brown and formed on stem, both sides of the leaves, leaf sheaths and spikes. Remnants of the epidermis which rupture during spore release are visible on the margins of the pustules giving it a ragged and torn appearance. Gradually the uredosori are replaced by black teliosori with ruptured epidermis.

Management:

a. Grow recommended varieties like HPW 155 (Onkar), HPW 236, HPW 249 (Asmi), HPW 89 (Surabhi), VL 829, VL892, VL 907, HS 490 and HS 507
b. Spray the crop with Tilt (propiconazole) 25 EC or Folicur (tebuconazole) or Bayleton (triadimefon) (0.1%), and Dithane Z-78 (zineb) 75WP (0.2%) at 15 days' interval from first appearance of disease symptoms.

B. Loose smut (*Ustilago segetum tritici*):

Symptoms:

The entire inflorescence/ ear except the rachis, is converted into black powdery mass of smut spores. These olive brown to black teliospores are often blown away by the wind, leaving behind bare rachis and remnants of other floral structures.

Management:

a. Grow resistant varieties like HPW 155, HPW 251, VL 829 etc.
b. Use disease free seed or treat the seed with Vitavax 75WP or Bavistin 50WP @ 2.5g/Kg seed or Raxil 2DS @ 1.0 g/kg seed before sowing. Seed can also be treated by dipping in 0.01% (100ppm) solution of Tilt 25EC for six hours and drying under shade before sowing.
c. Rogue out smutted plants as soon as they appear by covering ears with polythene bags and destroy them. This helps in producing disease free seed.

C. Hill bunt /Stinking smut (*Tilletia caries and T. foetida*):

Symptoms:

At the heading stage, infected spikes tend to be bluish green (or darker) in color and the glumes tend to spread apart slightly. The bunt balls often become visible after the soft dough stage. All the grains in the ear head art affected and the entire grain is converted into a bunt ball. The contents of infected grains are replaced by greasy dense mass of black spore enclosed by the seed coat and upon crushing produce smell like rotter fish. A slight reduction in plant height is typical of common bunt by caries.

Management:

a. Use disease free seed or treat the seed with Vitavax (carboxin 75WP or Bavistin (carbendazim) 50WP @ 2.5 g/kg seed befor sowing.
b. Avoid deep and late sowing.

D. Karnal bunt / Partial bunt (*Neovossia indica*):

Symptoms:

The disease is generally detected at the harvest time of the crop. In an ear only few grains and in a stool, few ear heads are infected by the pathogen. The grains are generally partially infected and rarely the entire grain is converted into a sorus. A mass of thick walled dark brown to black teliospores replaces a portion of the endosperm (normally embryo is not destroyed) and the pericarp may be intact or ruptured. Diseased kernels give off a fishy odor when crushed.

Management:

a. Sow the crop well in time, late planting results in more disease.
b. Use disease free seed or treat the seed with Bavistin or Vitavax @ 2.5 g/kg seed before sowing.
c. Spray the crop meant for seed production with Tilt 25 EC (0.1%) at flag leaf stage and 50% ear emergence (10-12 days after first spray).
d. Avoid excessive nitrogenous fertilizers and irrigation particularly at flowering stage.

E. Foliar Blights and Blotches:

Symptoms:

- **Spot blotch (*Bipolaris sorokiniana*):** Lesions are elongated to oval in shape and are generally dark brown in color. As lesions mature, centers often turn light brown to tan colored surrounded by an irregular dark brown ring.
- **Tan spot (*Pyrenophora tritici-repentis*):** Lesions first appear as tan to brown flecks which expand into large, irregular, oval or lens shaped blotches with a yellow or chlorotic margin. As these spots coalesce, large blotches are formed. The development of a dark brown to black spot in the centre of the lesion is the characteristic-symptom of the disease.
- **Alternaria leaf blight (*Alternaria triticina*):** Initially, small, chlorotic, oval or elliptical lesions appear, later they enlarge and become irregular in shape. The chlorotic borders of lesions may become diffused and turn light to dark brown in color.
- **Septoria blotch (*Septoria tritici and S. nodorum*):** Initial infection sites tend to be irregular in shape, oval to elongated chlorotic spots or lesions. The centers of the lesions turn pale, straw colored and slightly necrotic with numerous small black dots (pycnidia). The lesions of S. tritici blotch tend to be linear and restricted laterally while those of S. nodorum blotch are lens shaped.

Management:

a. Treat the seed before sowing with Thiram or Vitavax @ 2.5 g/kg seed.
b. Spray the crop meant for seed production with Dithane Z-7% (0.2%) or Tilt 25 EC (0.1%) at 15 days' interval from first appearance of disease symptoms.
c. After the harvest of crop, burn the plant residues.
d. Follow 2-3 years crop rotation, including non-host crops.

F. Powdery mildew (*Blumeria graminis tritici*):

Symptoms: Initially, white to pale gray, fuzzy or powdery colonies of mycelia and conidia appear on the upper surfaces of leaves and leaf sheaths, culms and sometimes on the ear heads. Host tissue beneath the fungal growth tum chlorotic or necrotic. Older fungal colonies turn yellowish gray and studded with black dot like fruiting structures (perithecia/cleistothecia).

Management:

a. Spray the crop at fortnightly interval with Karathane or Bavistin (0.1%).
b. Spray of crop with Tilt 25 EC or Contaf 5 EC (0.1%) alternate with the first appearance of disease at 15 days.
c. Grow recommended and moderately resistant varieties like HPW 236, HPW 89, VL 829, VL 907, HS 490 etc.

G. Flag smut (*Urocystis tritici*):

Symptoms: Black teliosori are produced in narrow stripes running parallel to th veins just beneath the epidermis of leaves, leaf sheaths and occasional the culms. Diseased plants often are stunted, tiller profusely and t spikes may not emerge. A severe infection usually induces the leaves roll. The epidermis of older diseased plants tends to shred releasing the teliospores.

Management:

a. Practice shallow sowing and avoid late planting.
b. Apply irrigation immediately after sowing in fields where disease is serious.
c. Dress the seed with Vitavax or Bavistin @ 2.5 g/kg seed before sowing.
d. Rogue out the affected stools and destroy them by burning.

H. Head scab/ Blight (*Fusarium* spp.):

Symptoms:

Initial infections appear as small, water soaked, brownish spots at the base or middle of the glume or on rachis. The symptoms then spread in all directions from the point of infection. A salmon-pink to red fungal growth may be seen along the edges of the glumes or at the base of the spikelet. Infected kernels shrink, sometimes permeated with mycelia and the surface of the florets totally covered by white matted mycelium. Premature death and bleaching of one or more spikelet's or rarely the entire ear is a common symptom. During prolonged warm, moist weather, spikelet's on early infected heads appear speckled as a result of black perihelia giving the scabbed appearance.

Management:

a. Use disease free seed and treat seed with Bavistin @ 2.5 g/kg seed before sowing.
b. Spray the crop with Tilt 25 EC (0.1%) immediately after head emergence.
c. Destroy crop residues by burning or ploughing it deep.

I. Yellow ear rot (*Corynebacterium tritici*) and Ear cockle (*Anguina tritici)*:

Symptoms: The infected plants fail to form ears. If ears are formed they become abortive with twisted or distorted stalks and bearing yellow slime. Infected plants that escape the gummy phase develop black galls known as cockles containing thousands of nematode larvae in the ear heads in place of the normal grains.

Management:

a. Rogue out affected plants and destroy them by burning.
b. Separate out the nematode galls from seed by floatation method in 5 per cent common salt solution.

8.2 Barley:

A. Rusts:

Symptoms: Yellow rust (*Puccinia striiformis*): Small yellow pustules arranged stripes are formed on the leaves. In severe attack leaf sheaths, awa glumes are also affected.

Leaf rust (*P. hordei*): Small brown irregularly scattered pustu sometimes gathered in small clusters are formed on leaves and are rare the sheaths and stalks

Management:

a. Sow resistant varieties.
b. Spray the crop with Tilt or Folicur or Baylet (0.1%) for effective management.

B. Powdery mildew (*Erysiphe graminis hordei*):

Symptoms: The symptoms of this disease are also much like to those on wheat. T fungus develops numerous superficial white colonies on all the abo ground parts of the plant. The white color of colonies changes to gray reddish brown. Later dark cleistothecia develop on mildew growth.

Management:

a. Grow recommended varieties.
b. Spray the crop at fortnightly intervals with Karathane or Bavistin or Tilt 25 EC or Contaf 5 EC or Bayleton (0.1%).

C. Stripe disease (*Drechslera graminea*):

Symptoms: Yellow stripes develop on leaf blades and leaf sheaths which soon brown resulting in drying up of the leaves. The plants become stunted s the leaves are shredded.

Management:

a. Treat the seed with 3g Vitavax + 3g Thiram (1:1) per kg before sowing.
b. Spray Tilt or Folicur (0.1%) as soon as the disease appears.
c. Practice field sanitation and 3-4 years' rotation with host crops.

D. Loose smut (*Ustilago nuda*):

Symptoms: The affected plants produce black smutted ears containing loosely held spore mass which is blown away by wind leaving behind the naked rachis.

Management:

a. Rogue out smutted ears as and when they appear and destroy them.
b. Use disease free seed or treat seed with Vitavax or Bavistin @ 2.5 g/kg seed or Raxil @ 1.0 g/kg seed.

E. Covered smut (*Ustilago hordei*):

Symptoms: The grains are replaced by black spore masses, which do not fall apart as in loose smut but are held together by the ovary wall and the glumes.

Management: Use disease free seed or treat the seed with Vitavax @ 2.5 g/ kg seed or Raxil @ 1.0 g/kg seed.

8.3 Rice:

A. Blast (*Magnaporthe grisea*):

Blast disease of rice is more prevalent in mid hill region of the state where high humidity and low night temperatures prevail. This disease affects almost all plant parts including leaves, stem, sheath, panicles nodes and grains.

Symptoms: On leaves, disease appears as small, brown lesions, which later on become spindle shaped with greyish centers and brown margins. Under favorable environmental conditions, these lesions expand rapidly and coalesce resulting in the complete necrosis of infected leaves giving them a burnt appearance. Similar kind of lesions also appear on the stem, nodes, sheaths, panicles, spikes and spikelet's. Infected plants produce lesser number of panicles with lighter grains. Sometimes heavy infection during early phase of growth causes death of the plants. Infection at the neck at node below the panicle results in neck blast. Neck infection is very destructive, causing production of unfilled grains and chaffy panicles or causing the entire panicle to fall over, resulting in considerable reduction in the crop yield.

Management:

a. Go for early planting of the crop in blast infested areas.
b. Use recommended doses of nitrogenous fertilizers.
c. Treat the seed before sowing with carbendazim (Bavistin 50 WP) or tricyclazole (Beam 75 WP) @ 2g/kg seed.
d. Grow blast resistant varieties like, HPR 2143, HPR 1068 Kasturi (Basmati) under irrigated ecosystem and HPR 1156 and VL Dhan 221 under upland conditions or a hybrid Arize 6129 which has been recommended for areas up to a height of 1000 mamsl.
e. Spray the crop with carbendazim (Bavistin 50 WP) @ 30 30 L water/ Kanal or tricyclazole (Beam 75 WP) @ 18 g/3 L water/Kanal with the appearance of the symptoms at 10 to 15 days' interval and at 5 to 10 per cent panicle emergence stage.

B. Bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae*):

Symptoms:

This is a typical vascular disease in which causal bacterium spread through the xylem vessels. Its symptoms appear in two distinct phases:

a. **Kresek phase**: This is the most destructive phase of this disease in the tropics resulting from early systemic infection in the nursery or from seed infection. Leaves roll completely, droop, turn yellow to grey and ultimately the tillers wither away.
b. **Leaf blight phase**: Leaf blight symptoms appear at booting or panicle emergence stage which are characterized initially by pale green to yellow colored stripes which later on turn straw colored with wavy margins on both the edges of leaves. As the disease progresses the entire leaf turn white or greyish and dries up. In humid weather, yellowish opaque and turbid drops of bacterial ooze may be observed on the surface of young lesions.

Management:

a. Use healthy seed. Dip the seed in 5 % common salt solution container (500 g salt dissolved in 10 L water) and remove light floating seeds. Take out the heavy seeds from the contaf M and dry under shade before sowing.
b. Grow HPR 1068, HPR 1156, Arize 6129 in BLB infested are and avoid cultivation of HPR 2143 as it is highly susceptible BLB.

C. False smut (*Ustilaginoidea virens*):

This disease is favored by high fertility conditions. However, its incidence has been observed to be more on high yielding rice varieties.

Symptoms: The disease manifests its effect only after flowering when the causal fungus transforms individual grains of the panicle into velvety green spore balls. Initially these balls are small which later enlarge to enclose all the floral parts. These spore balls are covered by a membrane that bursts due to increase in their size and the colour of balls changes to orange, yellowish green, green olive green and finally to greenish black.

Management:

a. Collect and destroy the infected panicles.
b. Use recommended doses of nitrogenous fertilizers.
c. Spray the crop with copper oxychloride (Blitox 50%) @ 90 g/ 30L water/ Kanal or propiconazole (Tilt 25 EC) @ 30 ml/ 30L water/ Kanal when panicles start emerging from the sheaths (booting stage) and repeat after 10 days of first spray if needed.

D. Brown spot (*Drechslera oryzae*):

This disease occurs more or less every year in mild or severe forms in almost all the rice growing areas of the state and is correlated with poor soil conditions.

Symptoms: On leaves symptoms appear as small, purple brown, oval spots which enlarge and become dark brown at the edges while remain pale yellow, dirty white, brown or grey at the center. These spots are surrounded by a yellowish halo and later coalesce to become irregular in shape. Badly affected leaves turn brown and dry out. On glumes dark brown spots are formed from where infection spreads in the grains. The infection of nodes causes the panicle to break and fall down which results in the formation of shriveled grains that are unsuitable for seed purpose.

Management:

a. Float seed in 5% Sodium chloride solution and exclude the floating seeds; treat the seed with Thiram @ 3 g/kg before sowing.
b. Use recommended dose of nitrogenous fertilizers
c. Spray the crop with mancozeb (Dithane M -45) or zine (Dithane Z-78) @ 75 g/ 30L water/ Kanal at 10 days' interval or spray propiconazole (Tilt 25 EC) @ 30 ml/ 30L water/Kanal after 45 and 65 days of transplanting.
d. Collect and destroy the infected plant material.

F. Sheath blight (*Rhizoctonia solani*):

This disease is very common in lower hills of the state and affects plan both in the nursery and after transplanting.

Symptoms: Symptoms initially appear on stem and sheath near the water level in t field. On sheaths oval, greenish grey lesions are formed, which increase in length and become irregular in shape. The lesions are greyish white with brown or purple margins which on coalition appear like a ribbon. Outermost sheath breaks and falls off and later on, whole plant withe out. In favorable weather, mycelium and sclerotic of the fungus visible on the stem and sheath.

Management:

a. Grow resistant cultivars in sheath blight infested areas.
b. Use recommended dose of nitrogenous fertilizers.
c. Spray the crop with carbendazim (Bavistin 50 WP) @30g/30 water/ Kanal as soon as the symptoms appear at booting heading stage by directing the spray towards the base of plant.

G. Sheath rot (*Sarocladium oryzae*):

Symptoms: The disease causes rot on the uppermost leaf sheath that encloses panicle. On the sheath, oblong to irregular, greyish or greyish bro lesions with brown margins appear which enlarge and coalesce so cover most of the leaf sheath. In severely infected plants, young pan remains within the sheath or emerge partially.

Management:

a. Use healthy seed.
b. Collect and destroy the infected plant materials.

H. Glume discolouration (*Sarocladium, Helminthosporium, Gerlachia, Curvularia* etc.):

Symptoms: Disease appears in the crop when the panicles are still inside the sheath and is characterized by small, round, brownish black spots on the glumes. Severe infection leads to darkening and rotting of glumes which produce light grains.

Management:

a. Use recommended dose of nitrogenous fertilizers.
b. Spray the crop with carbendazim (Bavistin 50 WP) @ 30 g, mancozeb (Dithane M-45) @ 75 g or copper oxychloride (Blitox 50 WP) @ 90 g/ 30 L water/ Kanal at 10 days interval starting from the panicle emergence.

I. Stem rot (*Sclerotium oryzae*):

Stem rot is an important disease in water logged and low lying areas of the state. Disease starts appearing at the time of flowering but becomes severe nearing maturity.

Symptoms: Disease starts as small black, irregular lesions on the outer leaf sheath near the water line. These lesions enlarge as the disease progresses. The stem softens and the plants lodge. Affected plants produce only shrivelled grains. On splitting open the stem, dark greyish mycelium may be seen within the hollow stem along with dark brown mustard like sclerotia of the fungus.

Management:

a. Collect and burn the rice stubble after harvesting of infected crop to reduce the source of primary inoculum.
b. Avoid continuous flooding of the field. Drain out water frequently.
c. Do not let the irrigation water flow from infested to the non-infested fields.
d. Grow Basmati cultivars in the infested fields.

8.4 Maize:

A. Banded leaf and sheath blight (*Rhizoctonia solani*):

Symptoms: The disease symptoms develop on leaves and sheaths as characteristic banded lesions that cover large areas of infected leaves and husks. The main damage occurs in humid conditions on cobs as brownish rotting showing conspicuous, light brown, cottony mycelium with small, round black sclerotic.

Management:

a. Deep plough the fields in summer.
b. Grow recommended varieties.
c. Use proper spacing.
d. Remove lower leaves.
e. Spray the crop with Bavistin @1g/L. vi. After harvest burn the infected residue.

B. Stalk rot (*Erwinia chrysanthemi* pv. *zeae*):

Symptoms: The rot occurs at the lower nodes and spreads up and down the stalk. The leaves start yellowing and drying. The infected tissues of the stalk ar soft, but later on turn into a dry mass of shredded and easily disjointed fibers. At this stage the plant topples down.

Management:

a. Grow recommended cultivars like Renuka (DKH-9705), early composite, Parvati.
b. Apply judicious doses of nitrogen and potassic fertilizers.
c. Avoid heavy nitrogen fertilizer.
d. Ensure proper drainage.
e. Apply the first dose of bleaching powder @ 16.5 kg/h at the time of sowing, second dose at earthing up and third dose at tasseling stage in heavily infected field.

C. Leaf blight (*Drechslera maydis* and *D. turcica*):

Symptoms: Infection appears on leaves, stalks, leaf sheaths, and ear husks. Lesion are large, spindle shaped or elliptical, with yellow green or chlorot halos surrounding the lesions. Often lesions may have dark red-brows borders. Lesions may merge resulting in blighting and killing the leaves.

Management:

a. Grow resistant and recommended varieties.
b. Avoid delayed sowing
c. Apply foliar fungicides like Indofil Z-78 or Indofil M-45 @ 1.5kg/750 1 of water /h, as the disease appears and weather conditions are conducive to disease development.
d. Plough under infected residue to reduce inoculum.

D. Brown spot (*Physoderma maydis*):

Symptoms: Small yellow to brown chlorotic lesions appear on leaf blades, leaf sheaths and stalks. Later the lesions on leaf midrib become dark brown to black spots. Severe infection leads to breaking of the stalk.

Management:

a. Grow resistant and recommended varieties.
b. Adopt crop rotation and field sanitation.
c. Spray the crop with Indofil M-45 @2.5g/L

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9. Modern Techniques of Pest Management

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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.

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10. Response of Insect Pest to Global Climate Change

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Abstract:

Climate change has emerged as a significant driver of ecological transformations worldwide, with profound implications for insect pests and their interactions with ecosystems. Rising temperatures, altered precipitation patterns, and changing seasonal cycles affect the distribution, abundance, and behaviour of insect pests, leading to shifts in their geographic ranges and phenology. Changes in life cycle timing can affect natural predator-prey relationships and crop pollination, while invasive species' expansion into new habitats disturbs established ecosystems. Extreme weather conditions brought on by climate change, such as heatwaves and storms, can have a direct effect on insect populations by causing mortality and habitat loss. Warmer temperatures, however, may also benefit some pest species by accelerating their rates of reproduction and cutting down on generation durations. In order to address the effects of insect pests in the context of climate change, it is necessary to adopt sustainable agricultural practices, integrate climate projections into pest management strategies, and create adaptable pest control techniques. Additionally, anticipating and controlling possible pest outbreaks depends on our ability to better understand the ecological relationships between insect pests and their surroundings. For limiting the negative effects of insect pests in a changing environment and promoting harmonious cohabitation with these creatures, a proactive approach combining scientific knowledge, technical improvements, and sustainable practices is essential.

Keywords:

Insect pests, elevated temperature, geographic ranges, ecosystem disruption, extreme weather, elevated CO_2*, pest outbreaks*

10.1 Introduction:

Christian de Duve once said, “The cost of our success is the exhaustion of natural resources, leading to energy crises, climate change, pollution, and the destruction of our habitat. If you exhaust natural resources, there will be nothing left for your children. If we continue in the same direction, humankind is headed for some frightful ordeals, if not extinction.” Indeed, the race of development has led humans to somewhere where they are unable to see the path, where they are driving the Earth. Global climate change also referred to as global warming or climate crises is one of the most pressing issues of our time. It is a phrase used to describe long-term modifications to the Earth's climate patterns, such as variations in temperature, precipitation, wind patterns, and other facets of the planet's climate system. Such shifts may be caused by large volcanic eruptions or changes in the sun's activity. However, since the 1800s, anthropogenic activities have been the greatest driver of climate change, particularly the burning of fossil fuels like coal, oil, and gas, deforestation, industrial processes, and agricultural practices, bringing a rise in atmospheric greenhouse gas concentrations. By trapping heat from the sun and raising temperatures, greenhouse gas emissions from burning fossil fuels act as a blanket over the planet. These gases include carbon dioxide, methane, nitrous oxide, and others. A gradual rise in global temperatures as a result of this trapped heat is known as global warming. According to IPCC, 2021 forecast, if greenhouse gas emissions are not drastically reduced, the biosphere is expected to warm by another two to five degrees by 2100, adding to the 1.1ºC warming that has already occurred since industrialization. The implications of global climate change are numerous and diverse. Changes in precipitation patterns, a rise in the frequency and intensity of extreme weather events (such as hurricanes, droughts, and heatwaves), a shift in ecosystems and habitats, and negative consequences on economies, agriculture, and human health are just a few of them.

10.2 Impact of Climate Change on the Global Ecosystem:

The effects of climate change on different ecosystems around the world are profound. Rapid changes in temperature, precipitation patterns, and other climatic factors can upset the delicate balances that the Earth's ecosystems have evolved and adapted to over millions of years. The following are some of the main effects of climate change on various ecosystems:

A. **Forests:** Both tropical and temperate forests are susceptible to the effects of climate change. More frequent and severe wildfires, insect outbreaks, and tree mortality could result from rising temperatures, altered rainfall patterns, and more frequent droughts. These elements have the capacity to change the biodiversity of forests, change their composition, and in some areas, turn them into grasslands or deserts.
B. **Coral Reefs:** Coral reefs are extremely susceptible to changes in ocean chemistry and temperature. Coral bleaching, a phenomenon when corals expel the symbiotic algae dwelling in their tissues, can be caused by warm waters. As a result, the corals appear white and may even perish. Coral reefs and other marine ecosystems are at risk from ocean acidification, which is brought on by the ocean's increased absorption of carbon dioxide.
C. **Polar Regions:** Glaciers, sea ice, and permafrost are melting as a result of the Arctic and Antarctic experiencing rapid warming. For arctic ecosystems and the animals that rely on them, such as polar bears, penguins, and seals, this has dire repercussions. Sea

ice loss affects hunting grounds and upsets the food chain, changing the predator-prey relationship.

D. Freshwater Ecosystems: Changes in precipitation patterns, glacier melting, and changing river flows are some of the ways that climate change affects freshwater ecosystems. Water shortage can result from decreased water supply, which can also have an impact on the distribution and abundance of aquatic species, especially in regions dependent on snowfall. The reproductive and migration patterns of fish and other freshwater creatures can be impacted by temperature changes.

E. Grasslands and Savannas: As a result of altered rainfall patterns and an increase in the frequency of droughts, changing climatic conditions may have an impact on grasslands and savannas. These modifications may result in alterations in the vegetation's composition, decreased productivity, and greater susceptibility to wildfires. The equilibrium between herbivores and vegetation can be altered by grazing animals and the ecosystems that support them.

F. Alpine Habitates: Mountain habitats are highly susceptible to climate change, including the alpine ecosystems. The upward movement of the tree line as a result of rising temperatures alters plant communities and may result in the loss of habitat for alpine species. The downstream effects of melting glaciers and less snow cover on water availability influence ecosystems and human societies.

G. Coastal Ecosystems: Increasing storm surges, coastal erosion, and rising sea levels all pose serious risks to coastal ecosystems like mangroves, salt marshes, and seagrass beds. These ecosystems act as vital habitats for many species and as safeguards against coastal flooding. The loss of biodiversity can cause them to stop working properly due to climate change.

"Climate change is not just about melting ice caps and rising temperatures; it is also a threat to the intricate web of life on Earth, including the vital role played by insects."

Insects, the tiny heroes of our ecosystems, are facing unprecedented challenges due to climate change. Their decline would have profound consequences for the balance of nature."

10.3 Significance of Insects:

All terrestrial ecosystems are biologically supported by insects. They govern populations of other species, cycle nutrients, pollinate plants, spread seeds, maintain soil fertility and structure, and serve as a significant food supply for other taxa (Majer,1987). Almost all representations of a food web in a terrestrial or freshwater ecosystem include insects as a fundamental component, despite the fact that the food-web structures in these two ecosystems are very different (Shurin *et al.,* 2005).

A. Diversity: Insects are the most diverse group of animals on Earth, with over a million known species and potentially many more undiscovered. They exhibit a vast array of sizes, shapes, colors, and behaviors, occupying almost every habitat on the planet.

B. Pollination: Many flowering plants depend on insects for pollination. As insects move from flower to flower in search of nectar or pollen, they transfer pollen grains, facilitating the fertilization of plants and enabling them to reproduce. This process is critical for the production of fruits, seeds, and the maintenance of plant biodiversity.

C. Decomposition: Insects play a key role in the decomposition of organic matter. They break down dead plants and animals, recycling nutrients back into the soil. Species such as beetles, flies, and ants are important decomposers, accelerating the decomposition process and contributing to nutrient cycling. Thus, insects play a crucial role in this process. For agricultural ecosystems to remain robust and productive, soil insects are crucial (Cock *et al.*, 2012).

D. Pest Control: Some insects act as natural predators or parasites of other insects, helping to regulate pest populations. Ladybugs, lacewings, and parasitic wasps are examples of beneficial insects that prey on agricultural pests, reducing the need for chemical pesticides and promoting sustainable pest management.

E. Soil Health: Insects like ants and termites enhance soil fertility and structure through their burrowing activities. They create tunnels that facilitate water infiltration, nutrient cycling, and the aeration of the soil, benefiting plant growth and overall ecosystem health.

F. Food Web Support: Insects occupy various trophic levels in food webs, serving as a crucial food source for many other animals, including birds, reptiles, amphibians, and mammals. Insects provide a high-energy food supply and contribute to the energy transfer and functioning of ecosystems.

G. Pollutant Breakdown: Certain insect species have the ability to break down and detoxify pollutants in the environment. For example, some species of beetles and flies can degrade organic waste, including animal carcasses and sewage, reducing the impact of these pollutants on ecosystems.

H. Seed Dispersal: Insects, particularly beetles and ants, play a role in seed dispersal. They carry seeds to new locations as they forage, aiding in the colonization of new habitats and contributing to plant regeneration and genetic diversity.

I. Ecological Indicators: Insects can serve as indicators of ecosystem health and environmental changes. Their population dynamics and species composition can provide insights into habitat quality, pollution levels, and the impacts of climate change, helping researchers and conservationists monitor and assess ecosystem conditions.

J. Cultural and Aesthetic Value: Insects have cultural significance and contribute to human enjoyment and fascination with nature. They are subjects of scientific study, artistic inspiration, and recreational activities like insect-watching and photography, promoting environmental education and conservation awareness.

Insects are the unsung heroes of our planet, silently contributing to essential ecological processes. We must confront climate change to ensure their survival and the health of our ecosystems."

10.4 Impact of Various Climate Change Variables on Insects:

10.4.1 Rising Temperature:

Insect physiology is extremely sensitive to temperature fluctuations, according to Vant Off's factor, an increase of 10ºC tends to cause their metabolic rate to about double. Temperature significantly impacts metabolism, metamorphosis, movement, and host availability, which affects the likelihood of changes in pest population and dynamics (Shrestha,2019). Numerous studies have demonstrated that rising temperatures tend to speed up insect growth, consumption, and movement. This can have an impact on population dynamics by changing traits including fecundity, survival, generation time, population size, and geographic range. The impacts of higher temperatures are more pronounced for aboveground insects than for species that spend the majority of their life cycle in the soil as soil is a thermally insulating substance that can buffer temperature variations and so lessen their influence (Bale *et al.,* 2002).

The rate of the global temperature increase in the upcoming years will determine future changes in insect population dynamics. By the end of the current century, climate models project that the average global temperature will rise by 1.8–4ºC (Johansen,2002; Karl and Trenberth, 2003; Collins *et al.*,2007).

Under scenarios of global warming, the severity of pest infestations is anticipated to worsen as ambient temperatures typically rise toward ideal levels for the growth and development of many insect pest species, potentially reducing thermal limitations on population dynamics. (Deutsch *et al.*,2008).

Climate change has a variety of effects on insect dynamics, including a geographical expansion, an increase in overwintering survival rates, and an increased risk of invasive insect invasion. Due to the expansion of insect vector ranges and rapid reproduction of insect vectors, insects are more likely to transmit plant diseases, biological control agents such as natural enemies may become more or less effective, etc. For example, Panthania *et al.*, (2020) found that environmental variables including temperature, precipitation, and humidity, in general, are the main regulators of the whitefly population. They found that population growth is positively correlated with high temperatures and high humidity levels.

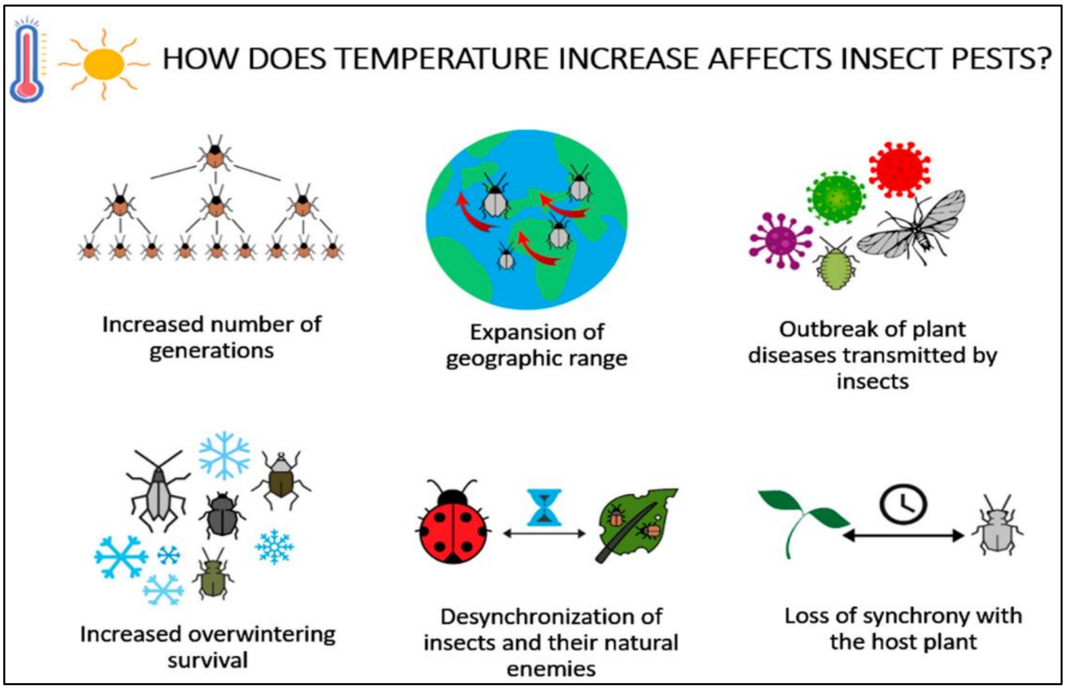

Figure 10.1: Effect of rising temperature on insects (Skendzic *et al.*,2021)

10.4.2 Elevated CO_2 levels:

The concentration of CO2 has increased by 30% from pre-industrial levels and is continuing to rise due to anthropogenic activities, there is currently a lot of concern about the impacts of elevated CO2 concentrations. According to Stiling *et al.,* (1999), the projected range of CO2 concentration in 2100 is between 540 and 970 ppm, up from roughly 280 ppm in the pre-industrial era. Changes in plant quality brought on by the elevated CO2 could have an impact on herbivory patterns and insect diversity and abundance as the key component for photosynthesis, a solar-powered process in which water and CO2 are transformed into sugars and starches, is CO2. The green pigments of leaves are where photosynthesis takes place, and CO2 must enter through stomatal holes (Rotter *et al.,* 1999).

Since carbon plays a crucial role in the structure of the plant, higher CO2 concentrations encourage quicker development because carbon is assimilated more quickly. The main impacts of high CO2 on plants include a decrease in stomatal conductance and transpiration, as well as better water and light use efficiency, and an increase in photosynthetic rate. As a result, increased atmospheric CO2 concentrations may have an immediate effect on ecosystems by promoting plant growth.

However, the effects may vary according to crop phenology, C3 crops (wheat, rice, cotton, etc.) would be more impacted by rising CO2 levels than C4 crops (corn, sorghum, etc.). As a result, the differential impacts of high atmospheric CO2 on C3 and C4 plants could have an asymmetrical impact on herbivory, and insects that feed on C4 plants might react differently than those that feed on C3 plants. While C4 plants are less responsive to elevated CO2 and thus less likely to be affected by changes in insect feeding behavior, C3 plants are more likely to be positively affected by elevated CO2 and negatively affected by insect reactions (Lincoln *et al.,* 1984).

Additionally, increased CO2 may change the primary and secondary metabolism of plants. Nitrogen levels in plant tissues are impacted by changes in the C/N ratio as a result of the increased carbon availability for plant tissues, which is known as the "nitrogen dilution effect". A lower concentration of leaf protein and therefore poorer nutritional value for herbivores result from this low nitrogen content, along with a high C/N ratio and its potential impacts on plant secondary metabolism (Lincoln *et al.,* 1986). Increased CO2 concentration causes some pest groups to consume more plants because nitrogen, a crucial component in the insect's body for development, increases the pace at which plants are consumed. Due to the fact that pests must eat more plant tissue to receive the same amount of food, this might result in higher amounts of plant damage. With compensatory eating, foliage feeders like caterpillars, miners, and chewers frequently increase their consumption rates in response to a decrease in nitrogen as predicted by CO2 fertilization (Hamilton *et al.,* 2005; De Lucia *et al.,* 2008)

10.4.3 Precipitation Patterns:

The amount, intensity, and frequency of precipitation are crucial climate change indicators. Precipitation has reduced in frequency while increasing in intensity, as has been seen in the majority of incidents. Droughts and floods have been more likely to occur in areas with this pattern of rainfall. Rainfall patterns that overlap have a direct impact on insect species that hibernate in the soil. In essence, persistent water stagnation and flooding are both caused by heavy rain. Flooding and subsequent soil waterlogging cause a number of changes in critical soil physicochemical parameters, such as soil pH, oxygen level, and redox potential, which can then result in hypoxia or anoxia and damage soil-dwelling insects in particular (Ashraf, 2012). Many riparian and soil-dwelling insects have developed numerous defenses to tolerate short-term hypoxia or anoxia (Harrison *et al.*, 2018; Hoback & Stanley, 2001; Woods & Lane, 2016), but longer-term soil flooding can exceed these defenses. Additionally, wet soil may push underground insects to the soil surface, where they are more exposed to attack by their natural enemies (Beirne,1970). Moreover, changes in soil conditions can lead to changes in above-ground primary and secondary plant metabolism that affects the performance of insects feeding on them (Ayres, 1993).

Flooding and severe rains also have the potential to sweep away insect eggs and larvae. When it rains heavily, small-bodied pests like aphids, mites, asides, whiteflies, etc. can be washed away (Pathak *et al.*, 2012). At the same time, rain changes microclimatic conditions such as temperature and humidity which are both important environmental variables affecting insect performance. The sudden drop in temperature during heavy downpours may reduce feeding activity and thus extend development time (Chen *et al.*, 2019). Insects like aphids and grasshoppers may thrive in environments with higher humidity, but pathogenic viruses and fungi may also spread more readily (Beirne,1970). Extreme rainfall may also have unintended consequences for insects by disturbing their natural environment.

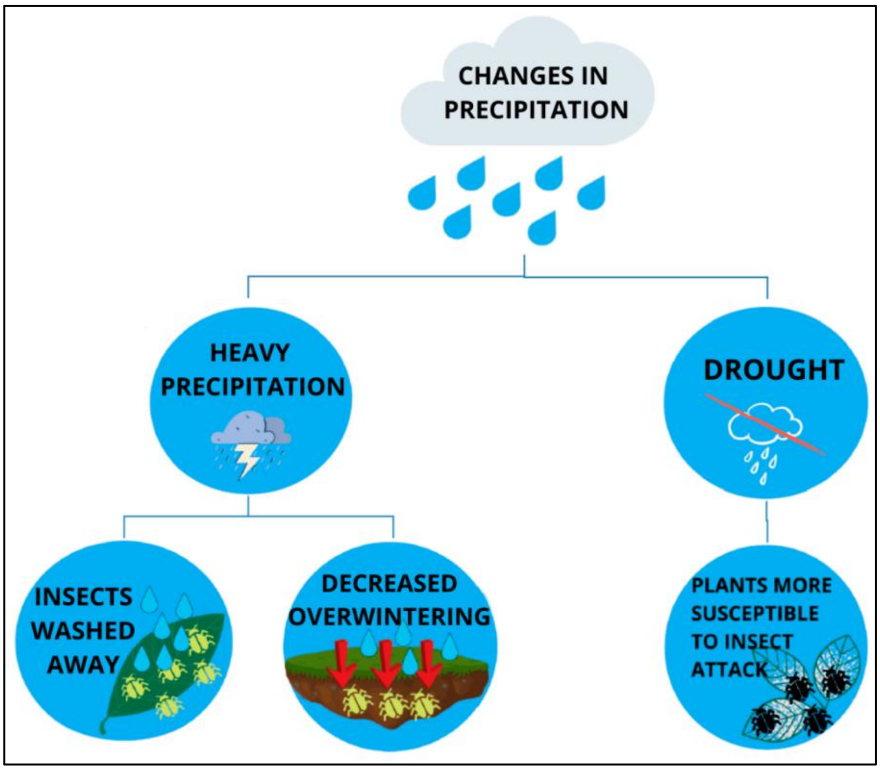

Figure 10.2: Impact of Precipitation Pattern on Insect Pest (Skendzic *et al.*,2021)

10.4.4 Drought:

Another climatic extreme that poses a risk to insects is drought. With above-average temperatures, heat waves, and frequent fires, extended (acute) droughts are lasting longer and becoming more intense in a number of different places (Dai, 2011; Williams *et al.,* 2022). The impact of drought stress on insects is complicated and depends on a number of variables. For instance, insects feeding on trees may react to drought very differently than insects feeding on forbs, sedges, and grasses, which are smaller plants (Gely *et al.,* 2021). Because small plants are more susceptible to water stress in the summer, drought episodes can reduce the populations of herbivorous insects on those plants as this results in a shortage of food resources, which has negative effects on population dynamics and interspecific interactions. Yihdego *et al.,* (2019) found that drought affects herbivorous insects in various ways such as:

- dry regions may offer favorable climatic conditions for their growth;
- drought-stressed plants may attract particular insect species. For instance, harmful bark beetles (Scolytidae) can detect the ultrasonic acoustic emission produced when water columns in the xylem separate or capitate during the process of transpiration;
- plants under stress from drought are more vulnerable to insect attack because the production of secondary metabolites with a defense function decrease.

Moreover, insect herbivore growth and development can also be impacted by changes in the concentrations of primary and secondary metabolites (such as defensive allelochemicals) and nutrients, such as amino acids and sugars, in foliar and root tissues under drought stress (Han *et al.,* 2016; Sconiers & Eubanks, 2017). Also, due to the need of water for the development of some insect eggs, droughts can impact reproduction too (Rohde *et al.,* 2017). Similarly, dryness can alter plant signaling and the quality of floral rewards for pollinators, which can reduce pollinator attraction and plant reproduction (Descamps *et al.,* 2018; Rering *et al.,* 2020).

10.5 Derived Consequences of Climate Change:

10.5.1 Expansion of Geographic Range:

The spread of insect pests is typically influenced by the following variables:

- Natural biogeography;
- Climate;
- Crop distribution;
- Agricultural methods being practiced (monocultures, irrigation, fertilizers, pesticides);
- Cultural trends and
- Trade (Ezcurra *et al.,* 1978)

Species-specific climatic requirements that are essential for their growth, development, reproduction, and survival highlight the geographic distribution and abundance of all organisms in nature. The distribution, survival, and reproduction of species in the future will be influenced by altered temperature and precipitation patterns as a result of the predicted changes in climate (Fand *et al.*,2012). Low temperatures are frequently more important than high temperatures in determining an insect pest's global range, and climate change will have a substantial impact on this (Hill,1987).

Farmers will face new and severe pest issues as a result of the expansion of insect pests to new locations and the change in the growing regions of their host plants. In such circumstances, other elements, such as soil characteristics and environmental structure, are of major significance in addition to meteorological conditions ideal for the specific crop (Lastuvka,2010)

10.5.2 Accelerated Generation:

Insect phenology is mostly impacted by temperature, which is the most significant environmental component. According to the ambient energy hypothesis, warmer temperatures promote increased growth and reproduction. Due to this relationship, rising temperatures or global warming can result in more species being in a state of dynamic equilibrium (Menéndez *et al.,* 2007; Menéndez, 2007). This makes it conceivable, under a scenario of global warming, to accelerate reproductive rates within a particular favored range, increasing the number of generations of many insect species and causing more crop damage (Yamamura and Kiritani,1998).

Univoltine and multivoltine temperate species will experience various effects from future temperature changes and to varying degrees. If all other factors are equal, higher temperatures should allow for faster development times that predictably allow for additional generations within a year for multivoltine insects like aphids and some lepidopteran species, like the large cabbage white butterfly (*Pieris brassicae* L.) (Bale *et al.,* 2002; Pollard and Yates,1993). The development of species tends to occur more quickly for those with yearly life cycles than for those with extended life cycles (Bale *et al.*, 2002). A 2 °C rise in temperature has been estimated to produce one to five extra life cycles every year using a number of models (Yamamura and Kiritani,1998). In this regard, aphids are especially notable, because their short generation period and low developmental threshold enable them to produce four to five additional generations per year. Temperature changes may, therefore, be detected more reliably by aphids (Menéndez, 2007). During their development, higher temperatures reduce the amount of time spent in the larval and nymphal stages (when they are very vulnerable to predators) (Bernays,1997) and allow species to reach adulthood sooner.

10.5.3 Overwintering Survival:

Due to their poikilothermic, or cold-blooded nature, insects have a constrained ability to maintain homeostasis in response to variations in the surrounding temperature. They have developed a number of coping mechanisms to survive in thermally hostile environments (Gonzalez *et al.*, 2020). Winter is the most important time of year for many insect pests because the low temperatures cause a significant rise in mortality, which lowers numbers in the following season (Hill,1987). According to studies, the effects of global warming are most noticeable in the winter at high latitudes (Pachauari and Reisinger, 2007). Many species in temperate and colder climates depend on diapause to overwinter, and it confers enhanced cold hardiness (the ability to survive at low temperatures) when it is not acclimated to low temperatures, which usually occurs naturally during the transition from summer to fall and winter (Pullin and Bale,1989)

Even though the current environmental conditions may be favorable, the seasonal response to photoperiodic has an adaptive relevance in that it stops further development and reproduction by gearing up metabolic activity for winter dormancy (Bradshaw and Holzapfel,2010). Additionally, given the intricate functions that insects play in the ecosystem, a number of additional processes, such as plant consumption, pollination, or interactions between species, occur concurrently with their diapause program. Thus, a single interruption of diapause caused by anthropogenic climate change might have a significant impact on the stability of the entire ecosystem.

10.5.4 Impacted Tri-Trophic Interaction:

The abundance, distribution, and seasonal timing of pests and their natural enemies will likely be severely impacted by climate change, which will modify the degree to which biological control efforts are successful (Thomson *et al.,* 2010). Temperature variations can have diverse effects on the biology of each species that makes up a system, which might disrupt their population dynamics (Hance *et al.,*2007) and lead to temporal desynchronization. Climate change is anticipated to have a considerable impact on natural enemies, which make up the third trophic level (Furlong and Zalucki, 2017)

If tropically connected species react to climate change in different ways, this could disrupt their trophic interactions, decoupling the synchronized dynamics between insect pests and their natural enemies and possibly impairing the effectiveness of biological control (Welch and Hardwood,2014). Hance *et al.,* (2007) reported that a too early and warm spring causes a natural enemy to emerge early and has a high likelihood of dying from lack of prey (for example, an aphid) if the natural enemy starts to develop at a slightly lower temperature than the prey and develops faster than the prey when the temperature rises. If this event persists for a number of years, the natural adversary can become extinct.

Moreover, Climate change is projected to cause changes in crop distribution ranges which may lead to Spatial desynchronization when herbivores follow these changes in crop distribution and move to locations where they may or may not be monitored by their predators or parasitoids (Hulle *et al.,* 2010).

10.6 Pest Management in a Changing Climate: Adaptation and Mitigation Strategies:

Climate change has the potential to significantly impact pest populations and their interactions with crops and ecosystems. Rising temperatures, altered precipitation patterns, and changing climatic conditions can create new opportunities for pests to thrive and expand their ranges, as well as disrupt the effectiveness of traditional pest management strategies. To address these challenges, adaptation, and mitigation strategies for pest management in a changing climate are crucial. Access to long-term data is one of the most crucial requirements for evaluating if climate change is changing the population dynamics of insect pest species (Yamamura *et al.,* 2006). It is very difficult to fully assess changes in pest populations under changing climate regimes and to anticipate future population dynamics without these crucial baseline data (Andrew and Hill,2017).

Some of the earliest indicators of biological reactions to climate change may come from long-term monitoring of pest populations and behaviour, particularly in climate change-vulnerable areas (Heeb *et al.,* 2019). In response to climate change, existing pest management techniques like detection, prediction, physical control, chemical control, and biological control need to be strengthened (Heeb *et al.,* 2019).

A global management strategy is required for monitoring and risk assessment to be successful due to the transboundary nature of many insect pests. Hence, a global system for sharing information between regions, including crucial data on insects, invasive alien species, diseases, and ecological conditions, including weather information is the need of the moment. Therefore, it is crucial to enhance cooperation across nations and regions, including national, regional, and international institutions (Perrings *et al.,* 2010).

Besides, in a changing climate, adopting an IPM strategy becomes even more crucial which combines different pest control strategies, including biological control, cultural practices, host plant tolerance, and the sparing use of pesticides. It emphasizes monitoring pest populations and making informed decisions based on thresholds, rather than relying solely on calendar-based pesticide application. Moreover, effective communication, education, and outreach programs are essential for promoting the adoption of climate-smart pest management practices. Farmers, agricultural professionals, and extension services should be provided with up-to-date information, training, and resources to understand the impacts of climate change on pests and to implement appropriate adaptation and mitigation strategies.

10.7 Conclusion:

In conclusion, it is evident that insect pests are significantly impacted by climate change. The changing climatic conditions, such as rising temperatures, altered precipitation patterns, and shifting seasons, create favorable environments for the proliferation and expansion of insect populations. These changes influence the distribution, abundance, and behaviour of insect pests, leading to detrimental effects on ecosystems, agriculture, and human health. The responses of insect pests to climate change are diverse and complex. Some species are expanding their ranges into previously unsuitable areas, causing invasive species problems and posing new challenges for pest management. Others are experiencing shifts in phenology, such as earlier emergence or extended breeding seasons, which can disrupt natural predator-prey relationships and crop pollination.

Addressing the impacts of insect pests in the context of climate change requires a multifaceted approach. It involves integrating climate projections into pest management strategies, promoting sustainable agricultural practices, and developing innovative and adaptive pest control methods. Furthermore, enhancing our understanding of the ecological interactions between insect pests and their environment is crucial for predicting and mitigating potential pest outbreaks.

Overall, climate change represents a significant challenge in managing insect pests. It highlights the urgency of implementing proactive measures to minimize the negative consequences on ecosystems, agriculture, and human well-being. By adopting sustainable practices and employing scientific knowledge and technological advancements, we can strive towards a balanced coexistence with insect pests, mitigating their impact while preserving the delicate equilibrium of our planet's ecosystems.

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11. Integrated Pest Management in Cereal Crops

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Abstract:

Pests pose a significant threat to cereal crops, leading to substantial losses in yield and quality. Insect pests, diseases, and weeds can severely impact cereal crops, reducing their productivity and overall agricultural output. The economic impact of pest damage in cereal crops is significant, as it results in reduced agricultural productivity, increased production costs, and decreased profitability for farmers. Additionally, Pest-related losses in cereal crops can have detrimental effects on food security, impacting local and global food supplies. To mitigate these losses, integrated pest management (IPM) strategies are employed, which include cultural practices, biological control agents, pest-resistant crop varieties and judicious use of pesticides. Regular monitoring, timely pest detection, and appropriate management interventions are crucial to minimize losses and maintain the productivity and sustainability of cereal crop production. The damage symptoms of major insect pests and their management strategies are discussed in this chapter.

Key words:

Insect pests, Cereal crops, Integrated pest management

11.1 Introduction:

Cereals have an important part in agricultural area, productivity, and nutritional composition across the world. India is a significant contributor to global cereal production, ranking second position in the production of rice, wheat, and other cereal crops. Cereals constitute an important part of the worldwide human diet and India specifically ranks as the second-largest producer of the rice, wheat and other cereals. However, these vital cereal crops face challenges from various insect pests, and other abiotic stresses. The emergence of insect pest problems is often linked to factors such as global warming, abnormal weather patterns and human intervention, such as changes in cropping patterns. Insect pests alone account for approximately 15.70% of crop losses in cereals (Dhaliwal et al., 2015). The introduction of high yielding varieties, the expansion of irrigation systems, and the wide spread use of increased amounts of agrochemicals, such as fertilizers and pesticides, have been implemented to enhance crop productivity. However, these practices have inadvertently led to significant crop losses caused by insect pests in certain crops. The primary elements contributing to this situation include the elimination of natural enemies, the resurgence of pests, developing resistance to insecticides, and the outbreaks of secondary pests.

The disruption of natural ecological balances and reliance on chemical treatments, insect populations have thrived and caused significant harm to created agricultural crops. This chapter mainly focuses on the symptoms of damage of pests and the Integrated Pest Management (IPM) for significant cereal crop pests such as rice, wheat, maize, and other millets.

11.2 Rice:

Rice crop being infested with number of pests and cause significant damage among them the Major insect pests of the paddy crop includes Yellow Stem Borer (*Scirpophaga incertulas Walker*), Brown Plant Hopper (*Nilaparvatha lugens* Stal), White Backed Plant Hopper (*Sogatella furcifera* Horvath), Leaf Folder (*Cnaphalocrocis medinalis* Guenee), Gundhi Bug (*Leptocorisa acuta* Thunberg), Gall Midge (*Orseolia oryzae* Wood-Mason)

A. Yellow Stem Borer (*Scirpophaga Incertulas*):

Yellow stem borer (YSB) is the serious insect pest of the rice crop. The female insect lays eggs in clusters on the leaves of upper surface. After a period 5-10 days, the eggs hatch, and the white larvae bore into the leaf sheath, causing patches of yellowish-white discoloration. As they continue to grow, they move into stem, resulting in “Dead hearts” at vegetative stage and also causes “White ears” during panicle stage.

B. Rice Gall Midge (*Orseolia Oryzae)*:

The rice gall midge is a significant pest that primarily affects rice plants during the tillering stage. It is characterized by the attack of only maggots, which inject a toxin called cecidogen into the growing stems. This toxin causes hollow, tubular galls known as silver shoots or onion leaves. Infestation by maggots results in excessive tillering and stunted growth of the rice plant.

C. Brown Plant Hopper (*Nilaparvatha Lugens)*:

The Brown plant hopper is the most damaging pest mainly in rice the growing regions of India. The infestation of BPH typically increases from the tillering stage to the panicle initiation stage, leading to severe yield losses.

Excessive nitrogen fertilizer usage, narrow planting spacing, judicious pesticide use, extended submergence of fields, and high humidity (>90%) with temperatures ranging from 25 to 32˚C all variables that encourage the development of BPH. Both nymphs and adults of BPH congregate above the water level at the base of the rice plant and feed from sap of the stem and leaf sheath.

Infested plants initially display yellowing leaves, which eventually turn brown as the plants dry up. This gives affected plants a burnt or scorch like appearance known as “hopper burn”. The hoppers excrete honeydew, which causes a sooty mold to form at the base of the affected plant. These are the vectors of Grassy stunt and ragged stunt disease.

D. Green Leafhopper (*Nephotettix nigropictus and Nephotettix virescens*):

Green leaf hopper is a sap-sucking insect that infests rice plants from the seedling stage to the panicle initiation stage. The favorable factors for development of the pest population are excess use of nitrogen, insufficient rainfall along with high temperatures and staggered planting. Green leaf hopper infestation leads to gradual yellowing of leaves, starting from tip and progressing downwards. It acts like a vector for Rice Tungro virus, Rice yellow dwarf and transitory yellowing.

E. Gundhi Bug (*Leptocorisa acuta*):

They attack rice crop during the flowering stage and continue up to milky stage. Both the nymphs and the adults use their piercing and sucking mouthparts to collect sap milky grains. As a result, the damaged grains become shriveled and retain a chaffy appearance.

F. Rice Leaf Folder (*Cnaphalocrocis Medinalis*):

The larvae fold the leaves by joining their margins together using silken threads. It resides within the formed tubes or rolls and consumes the chlorophyll present inside the leaves. The larvae’s feeding activity resulting in the production of whitish, membranous folded leaves, giving them a scorched appearance. Presence of longitudinal transparent whitish streaks is the major identification symptom.

G. Integrated Pest Management (IPM) for Rice:

- Selection of suitable resistant or moderately resistant varieties.
- Adoption of timely planting.
- Raising of healthy nursery.
- To minimize the overwintering population of insects, it is recommended to eliminate and disposing of rice stubbles during the initial ploughing after harvest.
- Removal of the alternate hosts and weed sps.
- Installation of pheromone traps for monitoring the pests.
- Before transplanting, clipping off the tips of seedlings can reduce the spread of the pests in main field.
- Alternate drying and wetting of crop and draining out of the standing water from field 2-3 times can reduce the BPH population.
- Formation of the alley ways at 2 meters’ distance, which promotes adequate crop aeration.
- Late sowing should be avoided to keep the gall midge infestation under control
- Mechanically passing rope over the crop 2-3 times during the tillering stage is an effective method to remove the larvae of the leaf folder.
- Using of some of natural enemies like *Trichogramma japonicum* egg parasitiod of yellow stem borer, *Trichogramma chilonis* for leaf folder.
- Seedling root dip method for the control of the yellow stem borer, dip the roots of the seedling in the chlorpyriphos solution (0.02%) for 12-14 hrs.

- Spraying of acephate 75 SP @ 1.5 g or cartap hydrochloride 50 SP @ 2 g or chlorantraniliprole 18.5 SC @ 0.3 ml of water or apply carbofuran 3G @ 10 kg or cartap hydrochloride 4G @ 8 kg or chlorantraniliprole 0.4% G @ 4 kg/acre to control the attack of yellow stem borer.
- For the management of the BPH chemically apply acephate 75 SP @ 1.5 g or buprofezin 25 SC @ 1.6 ml or imidacloprid + ethiprole 80WDG @ 0.25 g or dinotefuran 20 SG @0.4 g or tryflumezopyrim 10SC @ 0.485 ml or pymetrozine 50WG @0.6 g/l of water.

11.3 Wheat:

Wheat is one of the significant cereal crops in the world, playing a crucial role in global food security. Insect pests pose a significant challenge to wheat production worldwide, acting as important biotic factors which limit crop yields. The pests that cause economic damage to this crop include Termites, Wheat aphid, Armyworm, American pod borer, Brown mite, pink stem borer, Shoot fly, Wheat thrips and Ghujia weevil. Among them the damage symptoms of some significant pests are discussed here.

A. Termite (*Odontotermes obesus, Microtermes obesi*):

They cause damage to crops from the early sowing stage to nearly the maturity stage. The infestation of termites is more prevalent in un-irrigated fields. These pests feed on the roots, stems and even the dead tissues of wheat plants. Infested plants eventually dry up entirely and are easily uprooted.

B. Wheat Aphid (*Sitobian avenae, S. miscanthi*):

Both nymphs and adult aphids extract sap from the delicate portions of the plants by sucking. They typically target young leaves and ears, particularly during cold and cloudy weather conditions.

C. Pink Stem Borer (*Sesamia inferens*):

The Pink stem borer inflicts severe damage to crops by breaking the stem. Initially, larvae feed mostly on unfolding leaves, creating rows of oblong holes. The larvae penetrate into central shoot, causing the growing point to wither and resulting in the development of dead core in the young plants. Affected plants also exhibit the development of white ears. Dark circular ring-like cuts can also be observed on the lower most part of internodes of stem because of the feeding activity of the larvae.

D. Ghujia Weevil (*Tanymecus indicus*):

The pest is known to cause significant damage, particularly during the months of October and November. The adults of Ghujia weevil primarily consume tender leaves and shoots of wheat plants. It exhibits a preference for cutting germinating seedlings at ground level, often leading to the need for reshowing of affected areas. The grubs destroy the roots. Severe infestation is seen at the seeding stage.

E. Integrated Pest Management (IPM) for Wheat:

- Implementing summer ploughing is recommended to expose and eliminate the pupae of Ghujia weevil through sunlight exposure
- To protect wheat crop from damage caused by aphids, armyworm, shoot fly, *Helicoverpa*, it is advisable to avoid late sowing.
- Higher levels of nitrogen can attract larger populations of these pests, it is important to use the recommended dosage of nitrogenous fertilizers.
- Targeted spraying of the field borders can help to reduce the attack of aphids and minimize its damage inflicted to crop.
- To prevent damage caused by termites, it is advisable to consistently use well-rotted FYM.
- Mechanically destroy the termitaria.
- Installation of pheromone traps to monitor the presence of pink stem borers.
- Installation of the bird perches in the field@ 10 per acre can help facilitate the visits of predatory birds.
- Grow 4 rows of a barrier crops like sorghum or maize or pearl millet around the field.
- Treatment of seeds with chlorpyriphos @ 3-4 ml/kg of seed, use chlorpyriphos 50 EC @ 10 ml/l as a soil drench at sowing time in termite prone soils.

11.4 Maize:

In India maize holds the position of the third most significant cereal crop, following rice and wheat, both in terms of cultivation area and production. Presence of biotic and abiotic stress that hinder optimal yield potential. The three major insect pests of the maize include spotted stem borer (*Chilo partellus* swinhoe), Pink stem borer (*Sesamia inferens* walker) and Shoot fly (*Atherigona* spp) were previously the main concerns. However, since the report of invasive fall armyworm (*Spodoptera frugiperda* J.E. Smith) has raised concerns about maize production in the country, posing a significant challenge.

A. Spotted Stem Borer (*Chilo partellus*):

The larvae of the stem borer primarily consume the soft surface of the leaves before entering into stem through the whorl, where they consume the pith of the stem. They also feed on folded tender leaves causing characteristic symptoms resembling “shot holes”.

The infested plants exhibit stunted growth and may develop a condition known as “dead heart”. The larvae have the ability to migrate from other plants and enters the stem through lower nodes by creating bore holes.

B. Pink Stem Borer (*Sesamia inferens*):

During their early stages, the immature larvae of the *S.inferens* feeds on epidermal layer of the first three leaf sheaths. As they continue to grow, they drill into the central shoot of the plant, causing the drying up of the growing point. This results in a condition known as “dead heart” in young plants.

The presence of tiny punctures or elongated openings on the leaves indicates the visible signs of damage caused by the larvae. Additionally, exit holes can be observed on the stem, and the tunnels created by the larvae are filled with their excreta.

C. Shoot Fly (*Atherigona* spp):

The larvae of the shoot fly are commonly known as maggots, target seedlings that are 2 days to 3 weeks old. They bore into the shoot of the maize plant while feeding, resulting in the gradual destruction of the growing point. This leads to the withering of the central shoot, which is referred to as “dead heart”. The formation of dead heart typically occurs within 2 weeks of germination.

D. Fall Armyworm (*Spodoptera frugiperda*):

The first and second instar larvae of the fall army worm can be found on outermost part of the leaves, where they scrape the epidermis, resulting in elongated papery windows appearing on surface of leaves wholly. As the larvae reach the third instar and beyond, they settle in the whorl of the plant, and their feeding activity creates a series of holes in the unfurling leaves, accompanied by the presence of their faecal matter. As the larvae grow, their feeding rate increased, leading to larger holes and an increased amount of faecal matter. During the sixth instar stage, the larvae cause significant defoliation and leave a substantial amount of faecal matter in the plant whorl. Additionally, the larvae have the potential to attack the tassel and developing ears of the maize plant.

E. Integrated Pest Management (IPM) for Maize:

- Implementing deep summer ploughing and fallowing techniques can be beneficial in exposing the resting stage of pests. This helps in reduction of their population and controlling their damage.
- Inter-cropping maize with legumes, such as soybean, cowpea, or green gram, can help reduce the incidence of borers. These intercropping combinations are effective in managing pest populations.
- using well decomposed farmyard manure (FYM) can help reduce termite attack on maize crops. FYM incorporation enhances soil nutrient content and structure, making it less favourable for termites.
- Destruction of crop and removal of debris after harvesting the crop. Eradication of alternate host plants.
- Installation of pheromone traps for monitoring the incidence of pests in case of Fall Armyworm.
- Physically removing the neonates and egg masses helps in reduction of the pest population and protects from further damage to the maize plants.
- Remove dead hearts manually and destroy.
- Release of *Trichogramma chilonis* @ 1,60,000/ha on 7- and 15-days old crop and subsequently if needed.
- *Trichogramma pretiosum* or *Telenomus remus* (egg parasitoid) and *Completes chlorideae* (larval parasitiod) can be released to control Fall armyworm.

- Application of entomopathogenic fungi such as *Metarhizium anisopliae, Nomuraea rileyi, Beauveria bassiana* and *Verticillium lecanii.* Additionally use of bacteria like *Bacillus thuringiensis* var.kurstaki formulations are found effective for management of fall armyworm.
- When the damage reaches a level of 5% it is recommended to spray a solution of 5% NSKE (Neem seed kernel extract) or Azadirachtin at a concentration of 1500ppm.This solution should be mixed with 5 ml of water and applied during the seedling to early whorl stage.
- To control 2nd and 3rd instar of fall armyworm larvae, it is advised to spray specific insecticides during the mid-whorl to late whorl stage of the crop when foliar damage reaches around 10% Spinetoram 11.7% SC or Chlorantraniliprole 18.5% SC or Thiamethoxam 12.6% + Lambda cyhalothrin 9.5% ZC.

11.5 Sorghum:

Sorghum also known as jowar in India, cultivated globally, is a valuable source of fodder and fiber. *Sorghum bicolor,* originally from Africa, but now cultivated in various forms is a significant global crop with diverse applications. It is utilized for food consumption as grain and in production of sorghum syrup or "sorghum molasses". It is commonly known as Great millet and faces threats from several pests including stem borer, shoot fly, midge and white grub which can cause damage to crop. It faces threats from several insect pests such as stem borer, shoot fly, midge.

A. Shoot Fly (*Atherigona Soccata*):

Sorghum plants are damaged during the seedling stage which occurs between 5 to 30 days after emergence and they will exhibit characteristic symptom known as dead heart. During this stage, larva migrates towards upper side of leaf and moves within the leaf whorl until it reaches the growing point. At this point the larvae sever the growing point, causing the central leaf to wither and resulting in formation of dead heart. The dead hearts are easy to pull out and emits a foul odour due to rotting.

B. Stem borer (*Chilo partellus*):

The stem borer initiates its attack on the crop when it is around one month old, and continues till the appearance of ear heads. The borer's attack leads to the withering of central shoot, resulting in the manifestation of symptoms known as dead heart. Signs of infestation include the presence of bore holes near the nodes, minute holes on the delicate folded leaves resembling gunshot wounds and internal tunneling with stem.

C. Midge (*Stenodiplosis sorghicola*):

The midge is an insect that sucks the sap of cultivated sorghum and wild species, causing damage by feeding on the evolving grains and pupating with them. Infected plants display symptoms such as shedding of pollen, appearance of white pupal cases emerging from the grains and the grains with hole have chaffy appearance.

D. Integrated Pest Management (IPM) for Sorghum:

- To manage the infestation of stem borers, it is recommended to plant a single row of intercrop (lab lab or Dolichos) alongside four rows of sorghum.
- Perform thorough ploughing to bring the larval and pupal stages that reside in the stubbles to the uppermost layer.
- In the areas heavily infested by the *Atherigonia soccata* infestation, apply carbofuran 3G to the soil at the rate of 8kg per acre within the seed furrows.
- Remove and eliminate dead hearts dead hearts caused by stem borer infestation.
- Utilize pest-resistant or pest-tolerant varieties to combat pest infestations.
- Eradicate alternate hosts.
- For late sown crops affected by shoot fly infestation, use high seed rate of 4-5 kg/acre and subsequently thin out the affected and excess plants four weeks after sowing.
- Introduce biocontrol agents such as *Trichogramma chilonis*, *Bracon chinensis* and *Apanteles flaviceps* into the crop as a means of controlling the stem borer population.
- Seed treatment by using Imidacloprid at a rate of 7ml per kg of seed in combination with Thiomethoxam at a rate of 3 grams per kg of seed for shoot fly.
- To control the incidence of shoot fly, spray Thiodicarb at a concentration of one gram per litre or Lamdacyhalothrin at a concentration of 2 milliliters per litre at 7 and 14 days after the emergence of the crop.

11.6 Pearl Millet:

Pearl millet is the pre dominant variety of millet cultivated on large scale. It is a sustainable grain renowned for its abundant minerals and vitamins, making it a valuable source of nutrition. Pearl millet crop faces infestations from various pests with cut worms and white grubs being of national significance whereas grasshoppers, termites, stem borers, grey weevils, ear head bugs, ear head worms, blister beetles and chaffer beetles are considered insects of regional importance.

A. Cutworms (*Agrotis ipsilon*):

Cutworms are predominantly active during night time and have a tendency to feed on various agricultural and horticultural crops, especially during the seedling stage. During the initial larval stages, they create small irregular holes on leaves, while more mature larva cut the stalks of plants. Infested plants exhibit symptoms of wilting and, in some cases may die entirely.

The larva has tendency to cut plants beneath soil clods. In instances of high infestation, cutworms can result in significant crop losses, estimated at approximately 75 percent.

B. White Grubs (*Holotrichia consanguinea*):

White grubs are highly damaging insect pests for Pearl millet and they are most active during rainy season. These grubs primarily feed on underground roots of the crop, while beetles consume the foliage part during night time.

Affected plants display symptoms such as yellowing and wilting of leaves, as well as drying of entire crown. It becomes effortless to uproot the plants that have been affected.

C. Integrated Pest Management (IPM) for Pearl Millet:

- Adopting favorable cultural practices such as thorough summer ploughing, use of well decomposed farmyard manure, early sowing and crop rotation is recommended.
- To address the issue of cutworm infestation in the field, it is recommended to implement flood irrigation, conduct summer ploughing and manually remove the larvae during morning and evening hours.
- For managing cutworm infestation, it is advisable to install light traps at a density of 1per hectare and pheromone traps at a density of 12 per hectare to attract male moths. Additionally, applying neem oil at a concentration of 3% or chlorpyriphos 20 EC at a rate of 1 litre per hectare is recommended for spray treatment.
- Prior to sowing it is advised to mix in either 25 kg of Phorate 10G or 33kg of carbofuran 3G per hectare for grub control.
- Apply imidacloprid 17.8 SL at a rate of 2ml or chlorpyriphos 20EC at a rate of 6.5-12 ml per kilogram of seed as a seed treatment for grub control.
- To control white grubs, it is recommended to apply a drenching treatment within the root zone using chlorpyriphos 20 EC at a rate of 4 litres per hectare, three weeks after the emergence of adult grubs.

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12. Sucking Pest of Pulse Crop and Management

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Abstract:

Over the year's pulses have been a medium of sustainable crop production in the world. In India pulses are one of the major crops grown. Pluses can fix and use atmospheric nitrogen (under favorable conditions), potentially reducing the need for synthetic nitrogen fertilizer. This nitrogen-fixing properties of pulses improves soil fertility, which also improves and extends the productivity of farmland. But besides this, pulses are prone to get attacked by various insect, pests and diseases. Some of the major insect, pests of pulses include thrips, whitefly, leafhopper, black aphid, pod borers, stem fly, etc. There are several IPM practices which can be used to control these insects, pests.

Keywords:

Pulse, Crop, Production, Sustainable, Atmosphere

12.1 Introduction:

Pulses are one of the major crops grown in India. India is one of the leading producers of pulses. As per Second Advance Estimates, the estimated production of pulse crops for 2022-23 is 278.10 Lakh Tones (Ministry of Agriculture and Farmers Welfare). Pulses are annual crops which can be grown in Kharif, Rabi and Zaid seasons. Rajasthan, Madhya Pradesh, Maharashtra, Uttar Pradesh, and Karnataka are the top five pulse-producing states. Major pulses are grown chickpeas (gram), pigeon pea (tur or arhar), moong beans, urad (black matpe), masur (lentil), peas and various kinds of beans. Pulses are the nutritionally dense edible seeds of legumes. They are high-protein, high-fiber, rich in minerals and vitamins. According to the Indian Council of Medical Research (ICMR), 40 gm of pulses is the recommended daily intake for a balanced diet for an average sedentary man.

There has been tremendous increase in production of pulses in India, but pest attacks are also increasing which leads in damage and loss of yield. About 250 insects have been recorded feeding on pulse crops. Of these, about one dozen insects including pod borers, stem borers, leaf miners, foliage caterpillars, cutworms, jassids, aphids and whiteflies are most important. Some polyphagous insects also feed on these crops and cause considerable damage. The sucking pests which were earlier recognised as minor pests in pulses with lesser economic significance are attaining a status of major pests (Saxena et al. 2018). Productivity of pulses has been severely threatened by increasing difficulties in managing these sucking pests due to their ability to evolve resistance to insecticides, resurgence and their secondary outbreak due to indiscriminate and injudicious application synthetic insecticides. To attain economically feasible, ecologically sound, and socially acceptable management strategies against sap feeding pests of pulses, the detailed information on pest complex, their status and temporal association with host plant, yield losses, nature of damage, and feeding symptoms is of great significance.

12.2 What Are Sucking Pests:

The mouthparts of sucking insects are specialized for piercing and sucking. These pests damage plants by inserting their mouthparts into plant tissue and removing the juices or by sucking the cell saps. These sucking pests or sap feeders have an intense physiological effect on the growth of the host plant along with changes in both plant nutrients (Masters and Brown 1992) and plant secondary metabolites (Karban and Myers 1989). There are acknowledged in removing the nutrients from xylem or phloem of the host plant, thereby decreasing photosynthetic rates and plant growth (Meyer 1993). The pulse crops are affected by a number of sucking pests such as thrips, aphids, leafhoppers, plant bugs, whiteflies, scales, mealybugs, and mites which causes direct or indirect yield losses by attacking as vectors of viral diseases.

Table 12.1 Sucking Pests of Chickpea/ Bengal Gram

Sr. No.	Common name	Scientific name and family	Identification of pest	Nature of damage and symptoms	Control measures
1.	**Black aphid**	*Aphis craccivora* Koch Aphididae	Nymphs and Adult – dark coloured with cornicles in the abdomen	• Suck the sap from tender leaves, flower stalks and pods. • Leaves, inflorescence stalk and young pods covered with dark coloured aphids. Honey dew secretion with black ant movements	• Growing resistant varieties. • Spray of Acetamiprid @ 25g/100 L and Thiamethoxam @ 20g/100 L. • Use entomopathogenic fungus *Fusarium pallidoroseum* or *Beauveria bassiana* to cause epizootics in aphids. Lady bird beetles, Syrphids and green lacewings are reported as common predators of aphids.
2	**Pea aphid**	*Acyrthospihon pisum* (Harris) Aphididae	Adult aphids are soft bodied, long legged, pear-shaped, green yellow or pink in colour.	• Both nymphs and adults suck the sap from young shoots, ventral surface of tender leaves, inflorescence and even on stems. Curling and distortion of leaves, stunting and malformation shoots occur. Leaves turn pale and dry. Honeydew secretion of aphids leads to sooty mould which hinders the photosynthetic activity of the plants.	• Spray 1.0 L of dimethoate 30 EC in 750 L of water per ha when the attack starts and repeat after 15 days if necessary. • Use of entomopathogenic fungus *Pandora neoaphidis* has been reported to reduce *A. pisum* populations. • Lady bird beetles, green lacewings, hoverfly, damsel bug, minute pirate bug and various spiders are reported as common predators of aphids.

Sr. No.	Common name	Scientific name and family	Identification of pest	Nature of damage and symptoms	Control measures
3	**Cow bug**	*Tricentrus bicolor* Dist. Membracidae	Adults are black with prominent sub triangular pronotum overlapping the entire prothorax.	• Both nymphs and adults suck the plant sap and exude honeydew which attracts the black ant *Camponotus compressus.* • The damage caused is seldom severe resulting in drying of leaves/plant. The females cut tender branches,midrib of leaves,petioles,buds or lamina and lay eggs therein.	Spray of dimethoate at 2ml/ L
4	**Striped Mealy bug**	*Ferrisia virgata* Cockerell Coccidae	Nymphs are yellowish to pale white in color and adults are long, slender covered with white waxy secretions. Adult females have two longitudinal, submedian, interrupted dark stripes on the dorsum	• Mealybugs affect nutrient levels in plant by sucking the sap, thereby reducing growth, they often produce a sticky substance high in carbohydrates known as honeydew. • This honeydew is an excellent medium for growth of sooty mould fungus that forms a dark film on the leaf surface and impairs photosynthesis. Leaf discoloration and leaf and fruit drop are the markable symptoms of mealybug infestation.	• Debark vines and branches and apply methyl parathion paste. • Collect damaged bark, leaves, twigs and stems. • Use sticky traps on fruit – bearing shoots at a length of 5 cm. • Dimethoate 30 EC plus kerosene oil at 150 ml plus 250 ml in 100 ml of water. • Apply quinalphos dust in the soil at 25 kg/ ha to kill ants. • Release exotic predator, *Cryptolaemus montrouzieri* @ 10 beetles/vine. • Field release of parasitoids - *Anagrus dactylopii, Gyanusoidea mirzai.*

Table 12.2 Sucking Pests of Pigeon pea, Red gram or Tur

Sr. No.	Common name	Scientific name and family	Identification of pest	Nature of damage and symptoms	Control measures
1.	**Pod sucking bugs**	Clavigralla gibbosa Spinola (Spiny brown bug) Clavigralla scutellaris (West wood) Clavigralla tomentosicollis Stal.	**Spiny brown bug** • Adults are stout, about 10 mm long, furry and brown, having a pair of elongated spines projecting	• Both adults and nymphs feed by piercing the pod wall pf pigeonpea and sucking the sap from developing seeds. • The external symptoms of the damage are tiny	For all Pod sucking bugs Insecticides, particularly with systemic action such as acephate @ 1.0 g/l or dimethoate 1.7 ml/l are effective in controlling these pests.

Sr. No.	Common name	Scientific name and family	Identification of pest	Nature of damage and symptoms	Control measures
		Riptortus dentipes F.(Riptortus bug)	interiorly on pro-thorax. **Riptortus bug** • Adult bugs are slender and about 20 mm long. They are light brown with white or yellow lines on the lateral sides of the body.	depressions on the pod walls and seed coat. Affected seeds lose viability, shrivel and rot. • Both adults and nymphs feed by piercing the pod wall pf pigeonpea and sucking the sap from developing seeds. • The external symptoms of the damage are tiny depressions on the pod walls and seed coat. Affected seeds lose viability, shrivel and rot.	
		Anoplocnemis curvipes (Fabricius) (Hemiptera: Coreidae) (Coreid bug)	**Coreid bug** Adult is about 2.5cm long, causing damage similar to that of Clavigralla spp. Males have a single large spine on each hind leg, which is lacking in females. Newly hatched nymphs are bright red in colour, which gradually turn to black. There are five nyphals instars, initial stages resembling to ants.	• Both adults and nymphs feed by piercing the pod wall pf pigeonpea and sucking the sap from developing seeds. • Both adults and nymphs feed by piercing the pod wall of pigeonpea and sucking the sap from developing seeds.	
		Nezara viridula (L.) (Hemiptera: Pentatomidae) (Green stink bug)	**Green stink bug** Adults are about 1.2cm long, shield-shaped with an overall dull green color. The eyes are dark red or black. Small black dots can be found along the sides of the abdomen. The wings completely	• The green stink bug has piercing-sucking mouthparts consisting of a long beak- like structure called the rostrum. All plant parts are affected, however, growing shoots and developing pods are preferred. Attached shoots usually wither, or in extreme cases, may die. • The damage from the punctures are dark brownish or black spots. Pod growth is retarded, leading to withering and	

Sr. No.	Common name	Scientific name and family	Identification of pest	Nature of damage and symptoms	Control measures
			cover the abdomen.	dropping from the plant.	
2	**Cow bugs**	*Otinotus oneratus* W. *Oxyrachis tarandus* F. (Membracidae)	The adults are dark brown to black measuring approximately 7 mm in length and have horn-like projections on the thorax.	Nymphs and adults feed on sap from tender shoots. Heavy infestations during early growth of the crop may result in stunting and reduction of plant vigor. Cow bugs excrete honeydew, a sugary substance that attracts ants. The ants in return provide the bugs protection from natural enemies, which would otherwise keep cow bug population under check. The common name of cow bug is derived from this habit of providing 'milk' to the ants.	No specific control measures are recommended. Insecticides used to control major pests, particularly dimethoate 30 EC @ 1.7 ml/l reduce the population
3	**Leafhoppers**	*Empoasca fabae* (Harris) (Potato leafhopper)	Potato leafhopper Adults have pale to iridescent green bodies with 6 or 8 white spots on their pronotum They have a distinctive white H shape mark between their head and wing base.	• Both stages suck plant sap from tender plant parts, leaves and inject toxic saliva. • At high infestation levels stunted internodes can be observed. Visual damage caused by potato leafhopper is called "hopperburn". Hopperburn is not present until 5-7 days after leafhopper feeding has occurred. The first sign is yellowing of the leaf at the tip followed by necrosis and leaf curling. These symptoms are the result of the plant shutting down photosynthesis in the leaf in response to leafhopper feeding. As this pest weakens a plant, it becomes	No specific control measures are recommended.

Sr. No.	Common name	Scientific name and family	Identification of pest	Nature of damage and symptoms	Control measures
				more vulnerable to disease	
4	Mealy bugs	*Coccidohystrix insolita* (green)		• Crawlers congregate on leaves, stems and terminal shoots and suck the plant sap.	• Use of entomopathogenic fungus *Metarhizium anisopliae*
5	Scales	*Ceroplastodes cajani* Maskell *Icerya purchasi* Maskell (Hemiptera : Coccidae)		• Scale insects feed by sucking the fluids from tender stems, young shoots and leaves.	• Use of synthetic insecticides
6	Thrips	*Megalurothrips usitatus* (Bagnall) (Thysanoptera : Thripidae)	The black adults (1 mm) and nymphs are easily seen with the naked eye, particularly when they are on yellow flower petals.	• Adults and nymphs suck the sap from floral parts. • Heavy infestation of thrips can lead to shedding of buds and flowers.	• Insecticides such as dimethoate 30 EC @ 1.7 ml/l used to control major pests also reduce thrips' populations effectively.

Table 12.3 Sucking pests of Green gram, Black gram (Mungbeen, Urdbeen) and Cowpea

Sr. No	Common name	Scientific name and family	Identification of pest	Nature of damage and symptoms	Control measures
1	**Black aphid**	*Aphis craccivora* Koch Aphididae	Nymphs and Adult – dark coloured with cornicles in the abdomen	• suck the sap from tender leaves, flower stalks and pods. • Leaves, inflorescence stalk and young pods covered with dark coloured aphids • Honey dew secretion with black ant movements	• Growing resistant varieties. • Spray of Acetamiprid @ 25g/100 L and Thiamethoxam @ 20g/100 L. • Use entomopathogenic fungus *Fusarium pallidoroseum* or *Beauveria bassiana* to cause epizootics in aphids. • Lady bird beetles, Syrphids and green lacewings are reported as common predators of aphids.
2	**Coreid bug**	Anoplocnemis curvipes (Fabricius) (Hemiptera: Coreidae)	Adult is about 2.5cm long, causing damage similar to that of Clavigralla spp. Males have a single large spine on each hind leg,	• Both adults and nymphs feed by piercing the pod wall pf pigeonpea and sucking the sap from developing seeds.	• Insecticides, particularly with systemic action such as acephate @ 1.0 g/l or dimethoate 1.7 ml/l are effective in controlling these pests.

Sr. No	Common name	Scientific name and family	Identification of pest	Nature of damage and symptoms	Control measures
			which is lacking in females. Newly hatched nymphs are bright red in colour, which gradually turn to black. There are five nyphals instars, initial stages resembling to ants.		
3	**Green stink bug**	Nezara viridula (L.) (Hemiptera : Pentatomidae)	Adults are about 1.2cm long, shield-shaped with an overall dull green color. The eyes are dark red or black. Small black dots can be found along the sides of the abdomen. The wings completely cover the abdomen.	• Both adults and nymphs feed by piercing the pod wall of pigeonpea and sucking the sap from developing seeds. • The green stink bug has piercing-sucking mouthparts consisting of a long beak- like structure called the rostrum. All plant parts are affected, however, growing shoots and developing pods are preferred. Attached shoots usually wither, or in extreme cases, may die. • The damage from the punctures are dark brownish or black spots. Pod growth is retarded, leading to withering and dropping from the plant. • The females cut tender branches, midrib of leaves, petioles, buds or lamina and lay eggs therein.	• Insecticides, particularly with systemic action such as acephate @ 1.0 g/l or dimethoate 1.7 ml/l are effective in controlling these pests.
4	**Whitefly**	*Bemisia tabaci* Genn Aleyrodidae	Adult is a minute insect with yellow coloured body with white waxy bloom. Nymph is greenish yellow, oval in outline along with puparia on	• The damage is caused by both nymphs and adults, which are found in large numbers. They suck plant sap and lower its vitality. • Severe infestation results in premature	Spray any one of the following (Spray fluid 250 l /ha) • Methyl demeton 25 EC 500 ml/ha • Dimethoate 30 EC 500 ml/ha

Sr. No	Common name	Scientific name and family	Identification of pest	Nature of damage and symptoms	Control measures
			the under surface of leaves.	defoliation, development of sooty mould or honey dew and shedding of flowers and pods.	
5	**Lab lab bug**	*Coptosoma cribraria*	Nymphs and Adult - sub globular, oval and greenish shield bug.It has a characteristic buggy odour	• suck the sap • Cluster on the plant parts	• Use of synthetic insecticides
6	**Been mite**	• *Polyphagotarsonemus latus* *(yellow mite)* • *Tetranychus urticae*, *T. cinnabarinus* *(Red spider mite)*	Male mites are small and white to pale yellow in colour. Females are yellowish and bigger than the males. Adult - red or brown in colour	• Mite is seen on young leaves especially the top two to three leaves and the bud. • Affected leaves become rough and brittle and corky lines • Downward curling • Intermodes get shortened, • Shoots - stunted and deformed. • Nymphs and adults suck the sap from undersurface of the leaves • Affected leaves turn pale and have a dusty coating and fine webs. In severe attack the growth of the plants becomes stunted.	• Spray dicofol 18EC 2 ml/lit or ethion 50 EC 2 ml/lit • Application of wettable sulphur 80 WP 2g/lit using hand operated sprayer. • Spraying of dicofol 18.5 EC @ 2 ml/l or wettable sulphur @ 3 g/l

Table 12.4 Sucking Pests of Lentils

Sr. No	Common name	Scientific name and family	Identification of pest	Nature of damage and symptoms	Control measures
1	**Black aphid**	*Aphis craccivora* Koch Aphididae	Nymphs and Adult – dark coloured with cornicles in the abdomen	• suck the sap from tender leaves, flower stalks and pods. • Leaves, inflorescence stalk and young pods covered with dark coloured aphids • Honey dew secretion with black ant movements	• Growing resistant varieties. • Spray of Acetamiprid @ 25g/100 L and Thiamethoxam @ 20g/100 L. • Use entomopathogenic fungus *Fusarium pallidoroseum* or

Sr. No	Common name	Scientific name and family	Identification of pest	Nature of damage and symptoms	Control measures
					Beauveria bassiana to cause epizootics in aphids. • Lady bird beetles, Syrphids and green lacewings are reported as common predators of aphids.
2	**Pea aphid**	*Acyrthospihon pisum* (Harris) Aphididae	Adult aphids are soft bodied, long legged, pear-shaped, green yellow or pink in colour.	• Both nymphs and adults suck the sap from young shoots, ventral surface of tender leaves, inflorescence and even on stems. • Curling and distortion of leaves, stunting and malformation shoots occur. Leaves turn pale and dry. Honeydew secretion of aphids leads to sooty mould which hinders the photosynthetic activity of the plants.	• Spray 1.0 L of dimethoate 30 EC in 750 L of water per ha when the attack starts and repeat after 15 days if necessary. • Use of entomopathogenic fungus *Pandora neoaphidis* has been reported to reduce *A. pisum* populations. • Lady bird beetles, green lacewings, hoverfly, damsel bug, minute pirate bug and various spiders are reported as common predators of aphids.
3	**Green stink bug**	Nezara viridula (L.) (Hemiptera: Pentatomidae)	Adults are about 1.2cm long, shield-shaped with an overall dull green color. The eyes are dark red or black. Small black dots can be found along the sides of the abdomen. The wings completely cover the abdomen.	• Both adults and nymphs feed by piercing the pod wall of pigeonpea and sucking the sap from developing seeds. • The green stink bug has piercing-sucking mouthparts consisting of a long beak- like structure called the rostrum. All plant parts are affected, however, growing shoots and developing pods are preferred. Attached shoots usually wither, or in extreme cases, may die. • The damage from the punctures are dark brownish or black spots. Pod growth is	• Insecticides, particularly with systemic action such as acephate @ 1.0 g/l or dimethoate 1.7 ml/l are effective in controlling these pests.

Sr. No	Common name	Scientific name and family	Identification of pest	Nature of damage and symptoms	Control measures
				retarded, leading to withering and dropping from the plant. The females cut tender branches,midrib of leaves,petioles,buds or lamina and lay eggs therein.	
4	**Whitefly**	*Bemisia tabaci* Genn Aleyrodidae	Adult is a minute insect with yellow coloured body with white waxy bloom. Nymph is greenish yellow, oval in outline along with puparia on the under surface of leaves.	• The damage is caused by both nymphs and adults, which are found in large numbers. They suck plant sap and lower its vitality. • Severe infestation results in premature defoliation, development of sooty mould or honey dew and shedding of flowers and pods.	• Spray any one of the following (Spray fluid 250 l /ha) • Methyl demeton 25 EC 500 ml/ha • Dimethoate 30 EC 500 ml/ha
5	**Leafhopper**	*Empoasca kerri Pruthi (Cicadellidae)*	**Egg:** Elongated yellow-white egg is deposited in leaf vein. **Nymph:** Pale-green, wedge shaped, winged pads extend up to the fifth abdominal segment **Adult:** It is a wedge shaped and pale green insect	• Tips of affected leaves become brown, turn upwards and get dried up	• Spray dimethoate 30 EC 2ml/lit

Photo Plate

BLACK APHID

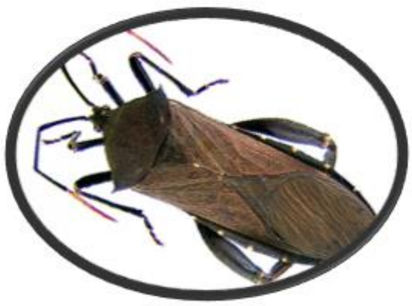
LEAFHOPPER

WHITEFLY

PEA APHID

GREEN STING BUG

RED SPIDER MITE



COREID BUG

LAB BUG

THRIPS

COWBUG

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13. Insect Pest of Vegetable Crops and Their Management

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Abstract:

Insect pests pose a significant threat to vegetable crops, impacting both yield and quality. These tiny marauders can devastate entire fields if left uncontrolled. Some common insect pests of vegetable crops include aphids, whiteflies, caterpillars, thrips, and beetles. Aphids and whiteflies are known for their ability to transmit plant diseases, while caterpillars, such as the infamous cabbage worm, chew through leaves and damage plants. Thrips cause stippling and discoloration, while beetles, like the Colorado potato beetle, devour foliage. Effective pest management is essential to protect vegetable crops. Integrated pest management (IPM) strategies combine biological, chemical, and cultural practices. These may include releasing natural predators, using insecticidal soaps or neem oil, crop rotation, and maintaining proper sanitation. Additionally, selecting pest-resistant crop varieties and employing physical barriers, like row covers, can reduce pest pressure. By integrating various control methods, farmers can minimize the impact of insect pests on their vegetable crops, ensuring healthier harvests and more sustainable agriculture.

13.1 Introduction:

Vegetable is a broad term that refers to the edible parts of plants, which are usually their leaves, roots, fruits, or seeds. Vegetables are a staple food across the world and are a fundamental part of modern agriculture. Vegetables are an important part of a healthy eating pattern and are excellent sources of many nutrients, including potassium, fiber, folate (folic acid) and vitamins A, E and C. These nutrients are vital for overall health and maintenance of body systems. India is the second largest producer of vegetables in the world (ranks next to China) and accounts for about 15% of the world's production of vegetables. Presently, India produces about 204.84 million metric tons of vegetables.

According to FAO (2021), India is the largest producer of ginger and okra among vegetables and ranks second in the production of Potatoes, Onions, Cauliflowers, Brinjal, Cabbages, etc. The major vegetable-producing states are Uttar Pradesh, Madhya Pradesh, West Bengal, Bihar, Gujarat, Odisha and Maharashtra. Though the vegetable requirement is 300g/day/person as recommended by dietician, we are able to meet only around 1/9th of that requirement. There have been various factors which are affecting the production of vegetables, one of the major factor is insect/pest attack on vegetables. Because of these insect/pest attacks farmers have to deal with heavy losses which indirectly causes decrease in production.

Major insects/pests infesting vegetables are Aphids, caterpillars, cutworms, grasshoppers and locusts, thrips, whiteflies, mites, etc. To attain relief from these insects/pests various IPM practices have been put forth.

13.2 Insect Pests of Solanaceous Crops (Tomato, Brinjal, Potato and Chillies):

13.2.1 Major Insect Pest of Tomato:

A. Tomato fruit borer
B. Leaf miner
C. Greenhouse whitefly
D. Fruit flies
E. Hadda beetles
F. Phytophagous mites
G. Thrips

A. Tomato Fruit Borer, *Helicoverpa armigera* (Noctuidae: Lepidoptera):

Figure 13.1: Tomato Fruit Borer

a. Identification:

- **Eggs:** yellowish white, ribbed, dome shaped and 0.4-0.5 mm in dia.
- **Larvae:** Newly emerged are yellowish white whereas older can be of many colors depending upon the food they consume. Full grown caterpillars are 40-48 mm long with whitish and dark gray longitudinal stripes.
- **Adults:** Medium sized stoutly built moths. Forewing is light yellow in males and brown in females. On the apical margin of forewings, wavy lines in the form of light black band are visible and a black spot appears on the upper side of the wing. On the tip of the abdomen there is a tuft of hairs in case of females, nevertheless, the tuft of hairs is absent in males.

b. Damage:

- Damage is caused by the larva

- Feed on the foliage, flowers, buds and fruits.
- Small green fruits are preferred
- Single larva can destroy many fruits
- The damage is more pronounced during March to June

c. Management:

- Deep summer ploughing to expose the pupae to the sunlight and natural enemies.
- African marigold as trap crop.
- Pheromone traps (5 traps/ ha) of moths for monitoring
- Spray of HaNPV @ 250 LE/ha at weekly intervals
- Bt formulation @ 0.5 Kg/ha.
- Periodic releases of egg parasitoid, *Trichogramma chilonis* or *T. pretiosum* @ 100000 /ha.
- Spray of NSKE @ 4.0 per cent
- Emergency spray of Imidacloprid 17.8% SL @ 0.03%, Emamectin benzoate 05 SG @ 0.002

B. Serpentine Leaf Miner, *Liriomyza trifolii* (Agromyzidae: Diptera):

Figure 13.2: Serpentine Leaf Miner

Identification:

- Eggs: Newly laid eggs are white, translucent and turn opaque as the development advances.
- Larvae: The larvae are orange yellow, apodous. They move through peristaltic action between the two epidermis. Full-grown maggots are1.88 x 0.70 mm.
- Pupae: Orange yellow initially which turn dark-brown on maturity. They measure1.84 X 0.68 mm.
- Adults: The adults are minute grayish black flies with plum red eyes and a yellow spot on the scutellum. The females are bigger (2.01x0.61mm) in size than males (1.79x0.52 mm).

Damage:

- Damage is caused by the larvae
- Feed on the palisade mesophyll tissue in between the two epidermis of the leaf.
- Infested leaves become transparent papery in the mined areas
- Photosynthesis is reduced.
- The attack appears during April and is more pronounced from June onwards.

Management:

- Severely infested leaves should be removed and destroyed.
- NSKE @ 4.0 per cent along with sticker is effective.
- The pest can be controlled by spraying the crop with deltamethrin (0.0028%) or imidacloprid (0.0075%).
- Natural enemies especially larval and pupal parasitoids are active during July-August.

C. Greenhouse whitefly, *Trialeurodes vaporariorum* (Aleyrodidae: Hemiptera)

Figure 13.3: Greenhouse whitefly

Identification:

- Greenhouse whiteflies are small insects with white coloured wings
- The eggs are 0.2 to 0.25 mm x 0.08 to 0.12 mm
- Newly emerged nymphs are light yellow in colour
- Last nymphal instar is 0.70 to 0.90 x 0.40 to 0.60 mm

Damage:

- Caused by nymphs as well as adults
- Suck the cell sap from leaves
- Leaves turn yellow and dry away.
- Nymphs also excrete honey dew on which sooty moulds develops
- Photosynthesis of the plant is reduced.

Management:

- Protect the nursery by using nylon nets (200 mesh) for 25-30 days.
- The pest can be controlled by need based spraying of crop with imidacloprid (0.0075%) or deltamethrin (0.0028%).

D. Fruit flies, *Bactrocera tau* (Tephritidae: Diptera)

Figure 13.4: Fruit flies

Identification:

- Adults are light brown with lemon yellow curved vertical markings across the thorax • On the apical margin of the forewing, grayish brown patches are present.
- Larvae are pale or reddish white which tapers anteriorly.
- The pupa is barrel shaped with dull to reddish yellow in colour.

Damage:

Damage is caused by larvae which feed inside the fruit on fruit pulp and the fruit is rendered unfit for human consumption.

Management:

- Collect and destroy the fallen infested fruits regularly on campaign bases
- Apply poison baits (40 ml malathion + 200g gur / molasses per 20L of water) in the form of spray or bait stations.
- Mass trapping of adults using cue lure
- Larval parasitoid, Biosteres dacusii also attack the pest in nature.

13.2.2 Major Insect Pest of Brinjal:

A. Brinjal shoot and fruit borer
B. Brinjal stem borer
C. Brinjal lace wing bug
D. Brinjal hadda beetle
E. Leaf hoppers
F. Whitefly
G. Aphid

A. Brinjal shoot and fruit borer, *Leucinodes orbonalis* (Pyraustidae: Lepidoptera)

Figure 13.5: Brinjal shoot and fruit borer

Identification:

- Full grown caterpillars are 15-18 mm long and light pink in colour
- Moths are medium sized with white wings.
- Fore wings have conspicuous black and brown patches and dots.
- Hind wings are opalescent with black dots along the margins.
- Wing span is 22-26 mm.

Damage:

- Damages the crop from seedling stage till the harvest
- In young plants, the caterpillars result in dead hearts
- Later on they bore into flower buds and fruits
- Enter from under the calyx, seal the hole with excreta
- The damaged flower buds are shed without blossoming
- Fruits show circular exit holes.
- These fruits become unfit for human consumption and lose market value
- Infestation up to 70 per cent may be recorded

Management:

- Install pheromone trap @12/ha.
- Encourage the activity of larval parasitoids: *Pristomerus testaceus*, *Cremastus flavoorbitalis*.
- Avoid use of synthetic pyrethroids and Avoid using insecticides at the time of fruit maturation and harvest.
- Spray any one of the following chemicals starting from one month after planting at 15 days interval Azadirachtin 1.0% EC (10000 ppm) 3.0 ml/lit., Emamectin benzoate 5 % SG 4 g/10 lit., Flubendiamide 20 WDG 7.5 g/10 lit.

B. Brinjal stem borer, *Euzophera perticella* (Phycitidae: Lepidoptera)

Figure 13.6: Brinjal stem borer

Identification:

- The eggs are cream coloured, scale like
- Full grown caterpillars are 16-18 mm in length and light brown in colour.
- Pupae are dark brown.
- Moths are medium sized, fore wings are pale rufous with distinct dentate vertical black lines
- Hind wings are whitish in colour.
- Wing expanse is 26 and 32 mm in male and female of, respectively.

Damage:

- Damage is caused by the caterpillars
- Feed inside the stem
- Bore in to the stem and move down ward
- The attacked plants wither and wilt, growth remains stunted and bear less fruits
- Infestation is generally seen in the late stage of the crop.

Management:

- Check the infestation at the initials stage by uprooting and destroying the infested plants.
- Release 1st instar larvae of green lace wing bug (*Chrysoperla carnea*) @ 10,000 Nos./ha.
- Parasitoids like *Pristomerus testaceous* and *P. euzopherae* are active in nature.

C. Brinjal lace wing bug, *Urentius hystricellus* (Hemiptera: Tingidae)

Figure 13.7: Brinjal lace wing bug

Identification:

- Nymphs are about 2 mm, pale, stoutly built with prominent spines.
- Adults are about 3 mm, straw coloured dorsally and dark brown to black ventrally. • Females are oval and males are elongated.
- Pronotum and elytra are reticulated
- Coastal area is hyaline with strong spines on the outer margins.
- Hind wings are whitish and transparent

Damage:

- Both adults and nymphs cause the damage by sucking the cell sap from leaves.
- Infested leaves show yellowish spots
- Excreta impart mottled appearance to the infested leaves.
- Young nymphs feed gregariously on the lower surface of the leaves
- Inject some toxic saliva.
- Under severe infestation upto 50% of the crop may be destroyed.

Management:

- Spray dimethoate 30 EC @ 1 lit/ha or methyl demeton 25 EC @ 1 lit/ha

D. Brinjal hadda beetle, *Epilachna vigintioctopunctata* (Coleoptera: Coccinellidae)

Figure 13.8: Brinjal hadda beetle

Identification:

- The grubs are about 6mm, yellow, with six rows branched spines.
- Beetles measure about 8 to 9 mm in length and 5 to 6mm in breadth.
- *vigintioctopunctata* beetles are deep copper coloured having 14 black spots on each elytron whose tip is somewhat pointed.

Damage:

- This pest beetles as well as grub scrape the chlorophyll from the epidermal layers of the leaves.
- They eat up regular areas of the leaf tissue, leaving parallel bands of uneaten tissue in between. The leaves, thus, present a lace like appearance.
- They turn brown, dry up, fall off and completely skeletonize the plants.

Management:

- Collect damaged leaves with grubs and egg masses and destroy them. Shake plants to dislodge grubs, pupae and adults and destroy.
- Conserve natural enemies in brinjal ecosystem.
- Use malathion 50EC @ 2ml/lit of water at 15 day intervals.

13.2.3 Major Insect Pest of Potato:

A. Potato tuber moth
B. Tobacco caterpillar
C. White grub
D. Green peach aphid
E. Whitefly

A. Potato tuber moth, *Phthorimaea operculella* (Gelechiidae: Lepidoptera)

Figure 13.9: Potato tuber moth

Identification:

- Egg: Laid singly on the ventral surface of foliage and exposed tuber
- Larva: Yellow coloured caterpillar with dark brown head
- Pupa: Pupation occurs within a cocoon among the trash, clods of the earth in the field
- Adult: Small narrow winged moth, greyish brown forewings and hind wings are dirty white

Damage:

- Larvae which mine the leaves, petiole and terminal shoots causing wilting.
- After tuberization, the larvae enter into the tubers and feed on them.
- Bore the tubers in stores also
- Larvae tunnel into the pulp which ultimately becomes unfit for use as seed or for human consumption.
- The infested tubers are further exposed to microbial infection which leads to rotting.
- The extent of damage to stored tubers varies from 20 - 85 per cent

Management:

- Plant tubers slightly deeper (10 cm) and follow proper earthing up
- Intercropping with chillies, onions or peas.
- Harvested potatoes should be lifted to cold stores immediately.
- If cold store facilities are not available, only healthy tubers should be stored.
- Cover the stored tubers with 2.5 cm layer of chopped dry leaves of Lantana or Eucalyptus or Eupatorium below and above the potato
- Mass trapping of adults with sex pheromones
- Under field conditions more than 20 traps/ha (sometimes up to 40 traps/ha) are required

- Spray of crop with quinalphos (0.375 kg a.i./ha) or acephate (0.5Kg a.i./ha)
- In stores dusting the tubers with 5% malathion or 1.5 5 quinalphos dust @ 125g dust/100 Kg of potatoes.
- Alternatively, dipping of tubers before storage with 0.0028% deltamethrin
- Bacillus thuringiensis has also been reported to suppress this pest.

B. Tobacco caterpillar, *Spodoptera litura* (Noctuidae : Lepidoptera)

Figure 13.10: Tobacco caterpillar

Identification:

- Egg: Masses appear golden brown
- Larva: Pale greenish with dark markings
- Adult: Forewings are brown in colour with wavy white marking, hind wings are white in colour with a brown patch along the margin

Damage:

- The young larvae first feed gregariously and scrape the leaves
- Older larvae spread out and may completely devour the leaves resulting in poor growth of plants.

Management:

- Plough the soil to expose and kill the pupae
- Grow castor along border and irrigation channel as trap crop
- Flood the field to drive out the hibernating larvae
- Set up light trap @1/ha
- Pheromone traps (Pherodin SL) @ 15/ ha to attract male moths
- Collect and destroy egg masses in castor and tomato

- Hand pick grown up larvae and kill them
- Spray Sl NPV @ 1.5X1012 POBs/ha + 2.5 Kg crude sugar + 0.1 % teepol

C. White grubs *Holotrichia sp* (Scarabaeidae : Coleoptera)

Figure 13.11: White grubs

Identification:

- Larva: "C" shaped grub
- Adult: Brown beetle with pale prothorax

Damage:

- Grubs feed on roots and tubers
- Grubs feed voraciously during night time

Management:

- Summer ploughing to expose pupae
- Dust Quinalphos 5% @25 kg/ha at 10 days after first summer rain
- Set up light trap @1/ha between 7 PM and 9 PM
- Handpick adult beetles in the morning

13.2.4 Major Insect Pest of /Chillies:

A. Chilli thrips
B. Green peach aphid
C. Tobacco cutworm
D. Gram caterpillar

A. Chilli thrips: *Scirtothrips dorsalis* (Thripidae: Thysanoptera)

Figure 13.12: Chilli thrips

Identification:

- Nymph: Are small, linear, easily fragile abdomen with straw yellow colour
- Adult: Fringed wings

Damage:

- The infested leaves develop crinkles and curl upwards
- Elongated petiole
- Buds become brittle and drop down
- Early stage, infestation leads to stunted growth and flower production, fruit set are arrested

Management:

- Inter crop with agathi (*Sesbania grandiflora)* to provide shade which regulate the thrips population
- Treat seeds with imidacloprid 70% WS @ 12 g/kg of seed
- Apply carbofuran 3% G @ 33 kg/ha or phorate 10 % G @ 10 kg/ha or
- Apply or Spray any one of the following insecticide Acetamiprid 20 SP 1.0g/10lit or Fipronil 5% SC 1.5 ml/lit or Spinetoram 11.7 SC 1.0 ml/lit.

13.2.5 Insect Pests of Cruciferous crops (Cabbage, Cauliflower and Broccoli)

A. Diamond back moth
B. Cabbage head borer
C. Cabbage butterfly
D. Cabbage green semilooper

E. Tobacco caterpillar
F. Cabbage aphid
G. Mustard aphid

A. Diamond back moth: *Plutella xylostella* (Yponomeutidae : Lepidoptera)

Figure 13.13: Diamond back moth

Identification:

- Egg: Minute yellow coloured eggs laid singly or in groups on the upper surface of leaves
- Larva: Pale yellowish green caterpillar
- Pupa: Pupation takes place on the foliage in a transparent cocoon
- Adult: Small greyish brown moth. Forewings have three white triangular spots along the inner-margin. Adult folds the wings that appear with triangular markings, opposite wing with diamond shape.

Damage:

- Young caterpillars cause small yellow mines on leaves
- Scrapping of epidermal leaf tissues producing typical whitish patches on leaves
- Full-grown larvae bite holes in the leaves and feeds on curd
- The infestation is more severe in dry season, when it causes growth retardation (under sized heads).

Management:

- Remove and destroy all debris and stubbles after harvest of crop
- Grow mustard as trap crop at 2:1 ratio (cabbage: mustard) to attract DBM for oviposition at least 10 days ahead of planting of main crop
- Spray mustard crop with dichlorvos 76 WSC 0.076% to avoid dispersal of the larvae
- Pheromone traps @12/ha

- Crop rotation with cucurbits, beans, peas, tomato and melon
- Larval parasitoid: *Diadegma semiclausm* @1,00000/ha (Hills–below 25–27ºC) *Cotesia plutellae* (plains) at 20000/ha release from 20 days after planting
- *Bacillus thuringiensis var kurstak*i 2g/lit
- Neem seed kernel extract 5%
- Spray any of the insecticides Spinosad 2.5%SC 1.2ml/lit or Emamectin benzoate 5SG 4g/10lit.

B. Cabbage head borer, *Hellula undalis* (Pyralidae: Lepidoptera)


Figure 13.14: Cabbage head borer

Identification:

- Caterpillars: Creamy yellow with a pinkish tinge and has seven purplish brown longitudinal stripes.
- Moths are slender, pale yellowish-brown, having grey wavy lines on the fore wings. Hind wings are pale dusky

Damage:

- Damage is caused by the caterpillars.
- Caterpillars first mine into leaves and feed on the chlorophyll
- Later on feed on the leaf surface sheltered within the silken passage.
- As they grow bigger they bore into the heads of cabbage and cauliflower.
- When the attack is heavy, the plants are riddled with caterpillars

Management:

- Collect and destroy mechanically caterpillars in the early stages of attack
- *Bacillus thuringiensis* @ 2g/lit at primordial stage
- Cartap hydrochloride @ 500g/ha or malathion 50 EC @500ml/ha
- The pest can also be controlled by spraying the crop with malathion @ 0.1 per cent.

C. Cabbage butterfly, *Pieris brassicae* (Pieridae: Lepidoptera)

Figure 13.15: Cabbage butterfly

Identification:

- Larva: Velvetty bluish green in colour with black dots, Yellow dorsal and lateral stripes covered with white hairs.
- Pupa: chrysalis which takes place in leaves and stem
- Adult: White butterfly

Damage:

- Young caterpillars feed gregariously and skeletonise leaves
- Late instars disperse and move to adjacent plants/ fields and feed on the leaves voraciously.
- Plants are sometimes completely defoliated resulting in heavy yield losses

Management:

- Collect and destroy caterpillars in the early stage of attack
- Conserve parasitoids like *Cotesia glomeratus*
- Spray insecticides like quinalphos 25 EC @1000 ml
- Collection and destruction of the egg masses and early gregarious caterpillars
- NSKE @ 4.0 % and Bt @ 500g/ha are also effective.
- Need based spraying of the crop with insecticides like malathion (0.05%) or cypermethrin (0.01%).
- In nature, Cotesia glomerata has been reported as major mortality factor of this pest.

D. Cabbage semilooper, *Thysanoplusia orichalcea* (Noctuidae: Lepidoptera)

Figure 13.16: Cabbage semilooper

Identification:

- Larvae: plump and pale green having three pairs of prolegs and are generally found mixed with the caterpillars of *P. brassicae*
- Adults: light brown with a golden patch on each fore wing and measures about 42 mm across the wings.

Damage:

- Larvae cause the damage by biting round holes into the leaves

Management:

- Hand pick and destroy the caterpillars
- Set up light trap @1/ha
- Spray insecticides like malathion 50EC @ 0.1% ha

13.2.6 Major Insect Pests of Cucurbit crops (cucumber, melons, gourds and squash)

A. Fuit flies
B. Pumpkin beetles
C. Stem gall fly
D. Snake gourd semilooper
E. Bottle gourd plume moth
F. Pumpkin caterpillar
G. Leaf miner

A. Fruit flies: *Bactrocera cucurbitae* (Tephritidae: Diptera)

Figure 13.17: Fruit flies

Identification:

- Eggs: Laid singly in clusters on fruits
- Larva: Dirty white apodous maggot
- Pupa: Pupate in soil

Damage:

- Maggots feed on the pulp of the fruits
- Oozing of resinous fluid from fruits
- Distorted and malformed fruits
- Premature dropping of fruits and also unfit for consumption

Management:

- Collect infested and fallen fruits and bum in deep pits.
- In endemic areas, change the sowing date as the fly population is low in hot dry conditions and at its peak during rainy season
- Expose the pupae by ploughing and turning over soil after harvest
- Use ribbed gourd as trap crop and apply carbaryl 0.15% or malathion 0.1% on congregating adult flies on the undersurface of leaves.
- Use attractants like citronella oil, eucalyptus oil, vinegar (acetic acid), and lactic acid to trap flies.
- Use poison baiting in severe infestation
- Mix methyl eugenol + malathion 50 EC at 1:1 ratio and keep 10 ml of the bait in polythene bags @ 25/ha.
- Use fly trap
- Keep 5 g of wet fishmeal in polythene bags (20 x 15cm) with six holes (3 mm dia)
- Add 0.1 ml of dichlorvos.

B. Pumpkin beetles: Red Beetle: *Aulacophora foveicollis,* Purple bettele:*A. cincta*, Ash beetle:*A. Intermedia*

Figure 13.18: Red Beetle: *Aulacophora foveicollis* (Chrysomelidae: Coleoptera)

Identification:

- Grub: Freshly hatched dirty white, fully grown grub creamy yellow in colour
- *Aulacophora foveicollis:* red in colour

  A. cincta: grey in colour having glistening yellow red border
  A. intermedia: blue in colour

Damage:

- Grubs feeds on the roots, stem and fruits touching the soil
- Adult feeds on leaf and flowers.

Management:

- Plough the fields just after harvesting destroy the hibernating adults
- Collect and destroy adult beetles
- Spray malathion 50 EC @ 500 ml

C. Stem gall fly: *Neolasioptera falcata* (Cecidomyiidae: Diptera)

Figure 13.19: Stem gall fly

Identification

- Adult: slender dark brown mosquito like fly

Damage

- Maggots bore into the distal shoot and form galls

Management

- Spray insecticide Malathion 50 EC @ 500 ml

D. Snake gourd semilooper: *Plusia peponis* (Noctuidae: Lepidoptera)

Figure 13.20: Snake gourd semilooper

Identification

- Egg: White spherical eggs laid singly on tender leaves
- Larva: Green in colour with longitudinal white stripe, humped last abdominal segments
- Pupae: Pupation takes place inside the leaf fold
- Adult: Brown moth with shiny brown forewings

Damage

- The caterpillar cuts the edges of leaf lamina, folds it over the leaf and feeds from within leaf roll.

Management

- Collect and destroy the caterpillars

- Encourage activity of *Apanteles taragamae, A. plusiae*
- Spray Malathion 50 EC @500 ml/ha

E. Bottle gourd plume moth: *Sphenarches caffer* (Pterophoridae: Lepidoptera)

Figure 13.21: Bottle gourd plume moth

Identification

- Egg: Eggs are laid singly on buds and leaves
- Larva: Small, cylindrical and yellowish green with short spines all over body
- Pupa: Greenish brown pupa
- Adult: Slender moth with lobed wings, fringed with scales

Damage

- Larva feeds on leaves making small holes

Management

- Collect and destroy larvae and pupae
- Spray Malathion 50 EC @500 ml/ha

13.2.7 Major Insect Pests of Okra:

A. Shoot and fruit borer
B. Okra fruit borer
C. Stem weevil
D. Red cotton bug
E. Whitefly

F. Jassids
G. Aphids
H. Leaf roller

A. Shoot and fruit borer: *Earias vitelli* (Nolidae: Lepidoptera)

Figure 13.21: Shoot and fruit borer

Identification:

- Egg: Sculptured egg and sky blue in colour
- Larva: Brownish with white streaks dorsally and pale yellow ventrally
- Adult: Forewing are pale with a wedge shaped green band in the middle

Damage:

- Terminal shoots wither and droop
- Shedding of buds and flowers
- Bore hole in fruits and fee
- Deformed fruits

Management:

- Set up pheromone trap @ 12/ha.
- Collection and destruction of affected fruits.
- Release of egg parasite *Trichogramma chilonis* @ 1.0 lakh/ha.
- Release of 1st instar larvae of green lacewing predator *Chrysoperla carnea* @ 10,000/ha.
- spray *Bacillus thuringiensis* @ 2 g/lit or spray any one of the following insecticide Emamectin benzoate 5 % SG 3.0 g/10 lit or Azadirachtin 5% Neem Extract Concentrate 5.0 ml/10 lit.

B. Okrafruit borer: *Helicoverpa armigera* (Noctuidae: Leidoptera)

Figure 13.22: Okrafruit borer

Identification:

- Eggs: Are spherical in shape and creamy white in colour, laid singly
- Larva: Shows colour variation from greenish to brown
- Pupa: Brown in colour, occurs in soil, leaf, and pod
- Adult: Female brownish yellow stout moth, Male is pale greenish in colour with V shaped markings

Damage:

- Feed on the flowers
- Circular boreholes on fruits
- Larva thrust only part of their body inside the fruit feed

Management:

- Collect and destroy the infected fruits and grown up larvae
- Grow simultaneously 40 days old American tall marigold and 25 days old tomato seedling at 1:10 rows to attract *Helicoverpa* adults for egg laying.
- Setup pheromone trap with Helilure at 15/ha
- Six releases of *T. chilonis* @ 50,000/ha per week coinciding with flowering time
- Release *Chrysoperla carnea* at weekly interval at 50,000 eggs or grubs/ha from 30 DAS
- Spray HaNPV at 1.5x1012 POB/ha along with cottonseed oil 300 g/ha to kill larva

C. Stem weevil: *Pempherulus affinis* (Curculionidae: Coleoptera)

Figure 13.23: Stem weevil

Identification:

- Grubs: Creamy yellow, apodous
- Adults: Dark greyish brown with pale cross bands on elytra

Damage:

- Grub feed on stem and galls are formed in the stem and petiole
- Adults feed on leaf buds and terminal shoots

Management:

- Soil application of Carbofuran 3 G at 30 kg/ha on 20 DAS and earthed up.
- Basal application of FYM 25 t/ha or 250 kg/ha of neem cake.

D. Red cotton bug: *Dysdercus cingulatus* (Pyrrhocoridae: Hemiptera)

Figure 13.24: Red cotton bug

Identification:

- Nymphs and Adults: Reddish bugs with white bands on the abdomen and black markings on the wings

Damage:

- Infested seeds become discoloured and shrivelled

Management:

- Conserve the biocontrol agent *Harpactor costalis* predaceous on nymph and adult
- Spray phosphamidon 40 SL @ 600 ml/ha

E. Whitefly: *Bemisia tabaci* (Aleyrodidae: Hemiptera)

Figure 13.25: Whitefly

Identification:

- Nymph: Greenish yellow, oval in outline
- Adult: Minute insects with yellow body covered with a white waxy bloom

Damage:

- Chlorotic spots on the leaves which latter coalesce forming irregular yellowing of leaf tissue
- Severe infestation results in premature defoliation
- Development of sooty mold
- Vector of yellow vein mosaic virus

Management:

- Spray any of the following insecticide Quinalphos 25 EC @ 2.0 l/ha or Phosalone 35 EC @ 2.5 l/ha

13.2.8 Major Insect pests of Onion and Garlic:

A. Onion thrips
B. Onion maggot or onion fly
C. Leaf eating caterpillars (cutworms, tobacco caterpillar, fruit borer)

A. Onion thrips, Thrips *tabaci* (Thripidae: Thysanoptera)

Figure 13.26: Onion thrips, Thrips

Identification:

- Eggs are tiny, kidney shaped and white in colour
- Nymphs and adults are slender, fragile and yellowish in colour
- Adults have fringed wings heavily with fine hairs.
- Males are 0.8-1.0 mm long while the females are 1.0-1.2 mm long

Damage:

- Damage is the caused by the adults as well as nymphs by lacerating the epidermis of the leaf and lapping the exuding sap.
- The affected leaves show silvery white blotches which later become brownish and get distorted form tip down ward, wilt and ultimately dry up.
- Heavy infestation at seedling stage results in retardation of growth and severe scarring of leaves which out rightly kill the seedlings. In case of heavy infestation at later stage the bulbs remain undersized and get distorted in shape.
- Attacked plants do not form bulbs and the flowers do not set seed. In Hawaii *T. tabaci* is known to act as a vector of the streak virus disease of peas and yellow spot disease of pine apple.

Management:

- Grow resistant verities of onion like White Persia, Grano, Sweet Spanish, Crystal Wax etc:
- The pest can also be controlled by spraying the crop with any of the insecticides like malathion @0.05% and dimethoate @ 0.03%
- After the application of insecticides observe a waiting period of 7 days

B. Onion maggot or onion fly, *Delia antiqua* (Anthomyiidae: Diptera)

Figure 13.27: Onion maggot or onion fly

Identification:

- Eggs are elongate in shape and white in colour
- Maggots are also white in colour and 18 mm in length when full grown
- Adult flies are slender about 6 mm in length and greyist in colour having large wings.

Damage:

- The maggots bore into the bulbs causing the plants to become flabby and yellowish. They mine thought the small bulbs completely, leaving only the outer sheath and thus causing a thin stand of the crop in the field.
- Larger bulbs are attacked by many maggots at a time by making cavities. The larger bulbs may not be destroyed by the attack but are subsequently rotten in the storage. It has been observed that onion maggots cause the initial damage which leads to the development of soft rot of onion caused by *Bacillus carotovorus.*

Management:

- Treat soil with phorate 10 G followed by irrigation
- Spray the crop with malathion @ 0.05% at 15 day interval is also effective.

C. Leaf eating caterpillars:

a. **Cutworms, *Agrotis ipsilion* (Noctuidae: Lepidoptera)**

Figure 13.28: Cutworms

Identification:

- Black with pale mid-dorsal stripes. Head is pale-brown
- Fore wing is pale brown with dark purplish brown along costal end. Hind wing is white with brown tinge. Male has bipectinate antenna and female has filiform antenna

Damage:

- Young larva feeds on tender foliage and grown up larva cuts the stem at collar region.

Management:

- Fork soil during summer months to expose larvae and pupae to avian predators
- Install light traps during summer to attract adult moths
- Install pheromone traps @ 5/ha to monitor and attract male moths
- Install sprinkler irrigation system to irrigate in day time to expose larvae for predation by birds
- In endemic areas, apply NSKE 5%, or neem oil 5 L in 500 - 750 L of water per ha. Focus nozzle at the collar region and apply insecticides during evening hours.

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ABOUT THE BOOK

"Emerging Trends in Plant Protection Sciences" is a seminal book that delves into the cutting-edge developments in the field of safeguarding agricultural crops from various threats. With chapters that explore the impact of climate change on insect pests, diseases, and pests of cereals and pulse crops, as well as the utilization of botanicals for plant protection, this book is a comprehensive resource for researchers, agriculturists, and policymakers alike. The chapter on "Impact of Climate Change on Insect Pest, Disease, and Pest of Cereals and Pulse Crops" addresses a pressing concern for agriculture worldwide. Climate change is causing shifts in the distribution and behavior of pests and diseases, posing new challenges to crop protection. This chapter discusses the adaptation strategies required to mitigate these threats and sustain crop yields in the face of a changing climate. The book explores the use of natural plant-based compounds as alternatives to synthetic pesticides. This eco-friendly approach is gaining prominence as it offers sustainable, non-toxic methods of pest control. Readers will discover the latest research and applications of botanicals, fostering a deeper understanding of their potential in integrated pest management. "Emerging Trends in Plant Protection Sciences" provides valuable insights into the future of agriculture, offering innovative solutions to protect crops against evolving challenges while promoting sustainable and environmentally friendly practices. It is an essential reference for those committed to ensuring global food security in the 21st century.

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