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2. Impact of Climate Change on Agricultural Insect Pests

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Abstract:

Over the past few decades, the escalating global warming resulting from climate change has become a critical global concern, posing a substantial threat to agriculture. Pests influenced by climatic factors, significantly impact crop growth stages, thereby decreasing agricultural productivity. Climate change causes include both natural factors like solar radiation changes and human-induced factors such as deforestation, industrialization, agribusiness practices and modernization. The impact of climate change on agricultural insect pests are direct, with temperature-driven impacts leading to shifts in species distributions and potential loss of sensitive species and indirect, involving altered synchronization between plants and pests influenced by elevated CO_2 levels and temperature changes. Studies project future scenarios for specific insect pests, predicting shifts in their distribution and habitat suitability based on climate change projections for 2050 and 2070. These scenarios highlight the potential impact on agricultural regions, emphasizing the need for adaptive strategies. Climate change exerts a complex and profound influence on insect populations, impacting growth rates, migration patterns, overwintering periods and overall biodiversity. This intricate interplay between rising temperatures, extreme weather events and shifting climatic conditions necessitates a comprehensive understanding for effective ecological and agricultural management. Mitigating the consequences of climate change on insect populations is crucial for ensuring food security, preserving biodiversity and maintaining ecosystem health.

Keywords: *Climate change, insect Pest, elevated CO_2 and increased temperature.*

2.1 Introduction:

The existence of life on Earth has become a major global concern in recent decades due to changes in the climate and its subsequent impact on global warming. In the last century, the average temperature of Earth has risen by 0.8°C and by the end of the next century, it is expected to rise by 1.1 to 5.4°C. Meanwhile, the concentration of carbon dioxide (CO_2) in the atmosphere has seen a substantial increase, going from 280 ppm (parts per million) to 370 ppm and it is expected to double by the year 2100 (IPCC, 2023). This transformation is primarily attributed to excessive exploitation and mismanagement of natural resources for various man-made development activities, including deforestation, rapid urbanization and industrialization. These activities have resulted in abnormal weather events such as altered rainfall patterns, more frequent floods and droughts, an increased frequency and intensity of heat waves and cold waves and outbreaks of agricultural insect pests. These changes have profound effects on various biological systems, ultimately impacting human beings as well (Pandi *et al.* 2018; IPCC, 2023).

The relationship between biotic (such as crop plants, weeds, insect pests, diseases and nematodes) and abiotic (such as temperature, humidity, rainfall, soil conditions and pollution) elements largely determine the ecology of the agro-ecosystem. The impact of these abiotic factors becomes most detrimental when they occur together, significantly affecting crop growth and productivity, with their combined influence reaching up to 80% (Mittler, 2006; Theilert, 2006). The abiotic environment, particularly those influenced by climate change, such as shifts in hydrological cycles and temperature patterns, can lead to changes the composition of agro-ecosystems. This in turn, results in shifts in the distribution and range of both animal and plant species at different altitudes (NACCAP, 2008). Therefore, given the current global climate change scenario, it is of utmost importance to address the combined stresses that pose a threat to the sustainability of agricultural production systems. The impact of pests during different stages of crop growth, influenced by climatic factors, is a significant factor that hampers agricultural productivity. In the context of global climate change, it becomes evident that insect pests that impact crop plants are the most vulnerable contenders. The complex physiological impacts resulting from rising temperatures and increased CO_2 levels can profoundly alter the interactions between crop plants and pests. Climate-related changes in insect pest conditions pose a serious threat to the country's agricultural output and people's health, especially in regions where a large percentage of the labor force works in climate-sensitive industries like agriculture (Chahal *et al.*, 2008; Deka *et al.*, 2008). In order to achieve the nation's aim of food security, it is anticipated that crop protection techniques will urgently need to be modified in light of the changing environment.

2.2 Climate Change:

“It is the long-term increase in the earth's average surface temperature and the large-scale changes in global, regional and local weather patterns that result from that increase, caused by a significant increase in the levels of greenhouse gases that are produced by the use of fossil fuels” (Gutierrez *et al.*, 2006).

“Climate change in Intergovernmental Panel on Climate Change (IPCC) usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity.”

2.2.1 Weather and Climate:

- **Weather:** The short-term local weather conditions, such as temperature, humidity, wind speed, precipitation, and visibility.
- **Climate:** The typical weather pattern or trend over an extended period of time, encompassing daily, annual, and even longer timeframes.

2.2.2 Global Warming and Climate Change:

Global warming and climate change are the two most often used expressions to describe the planet's rising temperatures. These have to do with long- and short-term patterns in the weather and environment. Although they are frequently used synonymously, there is one little distinction between the two:

- **Global Warming:** The rising mean temperature of the ocean and atmosphere, as well as the lower strata of the earth. The atmosphere of earth becomes warmer as a result of heat being trapped there by greenhouse gasses.
- **Climate Change:** The various environmental conditions in the planet that affect the weather patterns.

2.2.3 Impact of Climate Change on Insect Pests:

A. Directs Effects:

a. Effect On Population Growth Rate:

Temperature can have various effects on an insect species depending on its development technique. When extreme temperature events occur frequently and with severity, species with a high tolerance to heat will fare better than other species (Burgi and Mills, 2010). In insects that are tropical or subtropical, rising temperatures within specific ranges that are favorable to them speed up their rates of development, reproduction and survival. Insects will thus be able to reproduce more frequently each year, which will eventually cause greater agricultural damage (Bale *et al.,* 2002).

It has been evidently observed in the case of plant hoppers and aphids in recent times. According to estimates, insects may go through one to five more life cycles in a season if temperatures rise by 20°C (Pandi *et al.,* 2018).

Elevated temperatures not only help certain lepidopterans by attracting pests, but they also enhance their flying, which increases the probability of successful mating and increased egg laying. Increased metabolic rates and enzyme activity, such as that of midget proteases, carbohydrates and mitochondrial enzymes, are brought on by elevated CO_2 and temperature.

This could result in a rapid generation changeover of insect pests (Akbar *et al.,* 2016). According to Shrestha (2019), there could be a 10–25% increase in yield losses from insect pests for every degree temperature rises.

b. Effect On Migrating Behavior and Habitat Ranges:

It is predicted that as a result of global warming, species would be forced to change where they live, either by moving into previously unsuitable climates or by going extinct from unsuitable regions (Hughes *et al.*, 2003). Along with changes in the cultivation areas of their host plant, rising temperatures will enable insect pests to migrate from tropics and subtropics to temperate zones in higher altitudes. An increase in temperature of 1°C is expected to spread a species range 200 km northward or 140 km upward. This clearly illustrates how the expansion of insect ranges brought about by global warming would result in increased losses in crop yields in temperate areas. Additionally, it renders them susceptible to the introduction of new exotic pests that could endanger their agro-ecosystems. Pests with a wider geographic range than their main natural enemies pose the risk of escaping biological control or even causing epidemics. Unfortunately, viral diseases could become common in the near future and cause farmers to suffer significant crop losses due to the short life cycle and enhanced resistance of sucking insects (Sharma *et al.*, 2010).

The range expansion of agricultural insect pests and forest pests was predicted by several modeling studies. A few examples include the potential for significant yield loss and significant challenges for the management of pests in maize, as well as the altitude wise expansion of ranges and improved overwintering survival of the corn earworms *Heliothis zea* (Boddie) and *Helicoverpa armigera* (Hubner) due to global warming (Diffenbaugh *et al.*, 2008). According to Gutierrez *et al.* (2006), warming would enable the cold intolerant pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae), to spread its range on cotton into previously uninhabitable areas damaged by severe frosts. Damage percentage will also rise. Better situations for overwintering beetles, either larvae or adults, have been identified with the northward migration of the southern pine beetle, *Dendroctonus frontalis* (Williams and Liebhold, 2002).

c. Effect on Overwintering or Resting Periods:

The most significant shifts in their thermal environment are probably going to occur in insects going through a winter diapause (Bale and Hayward, 2010). Higher temperatures cause faster depletion of stored food resources, which shortens the length of insect diapause. Insects may have a delay in beginning the process of diapause due to winter warming and a quicker termination of the period in early summer may allow them to resume active growth and development. Warmer winter temperatures may contribute to lower insect mortality during the winter, which could lead to an increase in insect populations (Hahn and Denlinger, 2007). Aphids will survive longer in a warm, dry winter and multiply in wheat. When temperatures rise, *Heliocoverpa armigera* pupae may emerge from winter diapause up to 7 days early (Ouyang *et al.*, 2016).

d. Effect on Abundance and Biodiversity:

Climate change may cause a rapid shift in the relative abundance of many insect species and they are not able to survive such stresses may become extinct very soon (Jump and Penuelas, 2005). The species that inhabit mountains and high latitudes are expected to be more severely affected by rising temperatures and may be compelled to relocate from their natural range to even greater heights. Even if they can move, though, their range of habitable places will ultimately run out, and they may go extinct. Large scale differences in rainfall will have a significant impact on arthropod diversity and abundance in addition to temperature. Increased rainfall could potentially decrease the quantity of sucking pests like as aphids, trips, leaf hoppers and whiteflies. Insect pest outbreaks are caused by unusual weather incidents. For instance, red hairy caterpillar outbreaks can be caused by strong, frequent rains, and cutworm outbreaks can be caused by prolonged periods of drought followed by high rainfall (Sardana and Bhat, 2016).

B. Indirect Effects:

a. Through Host Plants:

- **Effect on Host Plant and Insect Pest Synchrony:**

Normally, the lifecycle of insects and the lifecycle of the plants it feeds on coincide naturally. However, because of variations in phonological responses of insects and their host plants, climate change is mainly having detrimental effects on ecological systems, leading to an increase in asynchrony (Visser and Holleman, 2001). When the growth cycles of the plants they eat change, many insect species that depend on those plants will be under pressure to adapt. As a result, an earlier time for larval and adult emergence as well as extended flight duration could be anticipated in insects (Menendez, 2007).

The winter moth (*Operophtera brumata*, Lepidoptera: Geometridae) shows phonological asynchrony with the wood host, the oak tree *Quercus robur*, where moth eggs take a risk by hatching early (Van-Asch and Visser, 2007). None of the 30 egg masses laid by the *Euphydryas editha* (Lepidoptera: Nymphalidae) bay checker spot butterfly hatched until after the host plants, Plantango and Castilleja, had undergone senescence. As a result, no larvae from these clutches were able to reach the third instar (Singer and Parmesan, 2010).

- **Effect of Increased CO_2 On Host Plants:**

The majority of C3 plants have higher rates of photosynthesis, therefore increased atmospheric CO_2 linked to global warming may encourage plant growth and increase the amount of food available. Initially, scientists believed that raising CO_2 would help ensure the world had enough food. However, it turns out that these optimistic forecasts were wrong. This is partly because, because the host plant is not as nutritious, insects consume more when growing in environments with higher CO_2 levels. By altering the nutritional makeup of the host plant, increased CO_2 can indirectly impact herbivore fitness, according to the "Nutrition Compensation Hypothesis." Due to the accumulation of non-structural carbohydrates and the 15–25% reduction in nitrogen in leaf tissues, it had a detrimental effect on insects. In response to this ratio, insects-particularly chewing ones like lepidopterans- have been shown to accelerate their feeding, a behavior known as "compensatory feeding" in which they consume more food to meet their metabolic needs for nitrogen, which allows them to obtain more amino acids. But hemipterans and other phloem and xylem-feeding insects might be less impacted by high CO_2 levels (Petzoldt and Seamann, 2010).

Many studies that investigated into how increased CO_2 affected various lepidopteran pests found that it lengthened the time of the larvae and pupae and reduced the weight and pupation rate. In addition, it contributed to low relative growth rate, higher relative consumption rate, and reduced efficiency of conversion of both ingested and digested food.

According to research, higher CO_2 raised 19% of phenols, 22% of condensed tannins and 27% of flavonoids, while it lowered 13% and 16% of terpenoids and nitrogen-based secondary metabolites, respectively. (Robinson *et al.,* 2012).

Four generations of the caster semilooper, *Archaea janata* (L.), have been seen to exhibit increased digestibility and lower efficiency of ingested food conversion into body matter under increasing CO_2 (> 550 ppm) (Srinivasa Rao *et al.,* 2013). Akbar *et al.* (2016) found that there was an increase in the rate of consumption of *Helicoverpa armigera* due to higher activity of digestive and mitochondrial enzymes. The populations of the potato aphid, *Macrosiphum euphorbiae* (Sudderth *et al.,* 2005), wheat aphid, *Sitobion avenae* (Zang *et al.,* 2018), and brown plant hopper (BPH), *Nilaparvata lugens* (Prasannakumar *et al.,* 2012), have grown due to elevated CO_2.

- **Effect of Increased Temperature on Host Plants:**

The elevated temperatures accelerated up the process of photosynthesis in the host plants, which improved the nutritional value of these plants. It has been demonstrated to indirectly increase insect herbivory by altering host plant growth potential, which causes a pest outbreak (Visser and Both, 2005). Furthermore, this will impact the synthesis of secondary metabolites and other protective characteristics in plants, making them more susceptible to insect attack.

Furthermore, some research has demonstrated that high temperatures have negative impacts on herbivores, such as shortened developmental times and increased usage of plant resources by other herbivores. Zhang *et al.* (2018) found that *S. litura* larvae fed on soybean grown at increased temperature as compared to ambient temperature significantly decreased in terms of larval duration, pupal duration, and pupal weight. Reduced host defenses brought on by temperature stress may be the cause of *H. armigera* early starting of infestation in cotton and pulses in Northern India (Sharma, 2010).

- **Effect on Host Plant Distribution:**

Climate change has an impact on the geological distribution of plant species as well as their developmental processes. The distribution of insect pests would be impacted by shifts in the range and quantity of its cultivated and uncultivated host plants. It's possible for new pests to emerge and certain pests may spread to new locations as a result of their host plants' wider distribution. In their modeling study on the global distribution of the Colorado potato beetle, Wang *et al.* (2017) revealed the risk of beetle invasion from its native range, which includes most of southern and central North America (Mexico and the United States), to non-native areas, such as northern, central, and southern Africa and Asia, including Madagascar, Asia Minor, Pakistan, India, Bangladesh, Nepal, much of eastern China and large areas in Australia.

b. Through Natural Enemies:

Effective biological control of insect pests depends primarily on our ability to learn how natural enemies of insect pests respond to climate change. Natural enemies are impacted by climate change in a very complicated way. Global warming will alter the relationships between pests and their natural enemies, which will lead to changes in the status of particular pest species, both positively and negatively.

- **Effect on Biology of the Natural Enemies:**

For the effective biological management of insect pests, natural enemies must be able to locate, combat, and eat their prey on a per capita basis. The efficiency of biological control will change as a result of direct effects of climate change on the physiology and behavior of natural enemies and prey. The chemistry of host plants may change as a result of rising CO_2, while rainfall's unpredictable patterns may have a variety of effects. On the other hand, warming will have the biggest direct impact on the biology, ranges, and phonologies of predators and prey.

The most significant rates of prey attack and intake were typically found to be close to 24°C and 26°C, respectively. This suggests that average temperatures that remain above these values over time may start to disrupt biological regulation. Higher CO_2 could allow generalist predators or parasites to control pests more successfully than specialists can (Eigenbrode *et al.,* 2015). Dyer *et al.* (2013) found that armyworm parasitism and the risk of its spread were low due to the caterpillars' brief growth stage while eating on Lucerne in environments with high CO_2 and temperature.

According to study by Klaiber *et al.* (2013), there has been a roughly 50% decrease in the number of the specialized parasitoid *Diaeretiella rapae*, which feeds on aphid hosts. Warming may disrupt biological control, as evidenced by the parasitic wasp *Cotesia marginiventris* Cresson (Hymenoptera: Braconidae), which developed successfully at 26°C but failed to finish developing in its host, *Spodoptera exigua* Hubner (Lepidoptera: Noctuidae), at 33°C (Butler and Trumble, 2010).

- **Effect on Insect Pest-Natural Enemy Synchrony:**

The co-occurrence of the pest's vulnerable stages and the natural enemy's attacking stages in time is crucial for the effectiveness of biological control programs, particularly those that involve classical and conservation biology and depends on the target pest and natural enemies being in adequate synchrony. Temporal asynchronies between interacting populations may even cause the natural enemies to perish as a result of the changing climate setting (Karuppaiah and Sujayanad, 2012).

There is a wealth of research on the topic of parasitoid and host synchronization problems. Based on ten years of data, Evans *et al.* (2012) discovered that during warmer springs in Cache Valley, Utah, the introduced specialist parasitoid wasp, *Tetrastichus julis* Walker (Hymenoptera: Eulophidae) and the cereal leaf beetle, *Oulema melanopus* L. (Coleoptera: Chrysomelidae), were asynchronously observing one other.

- **Effect on Interspecific Interactions of Natural Enemies:**

The two natural enemy species different rates of development are affected by rising temperatures, which also affects the overall number of natural enemies in the ecosystem. Long-distance dispersing natural enemy species have the potential to spread their range faster and contribute more to biological control than species with less dispersal capacity. Because many parasitoids are highly dependent on a particular host, we may also anticipate that they will be disproportionately affected by climate change in comparison to generalist natural enemies (Gilman *et al.*, 2010). According to Bruce *et al.* (2011), warming may have an impact on the volatiles that the host plant produces, which could change how natural enemy communities search and feed.

2.2.4 Impact of Climate Change on Pest Management:

- Increased temperatures, Ultra Violet (UV) radiation and decreased relative humidity might reduce the effectiveness of certain pest management measures, including host plant resilience, natural enemies, bio-pesticides and synthetic insecticides. Because agricultural rotations and the cultivation of crops in non-traditional places will change as a result of climate change. However, changes in cropping patterns as a result of climate change will drastically affect the balance between insect pests and their natural enemies (Maiorano *et al.,* 2013).
- Some cultural package of practices like crop rotation, early or late sowing or planting and other cultural practices will be less or ineffective due to agricultural growing season reductions, early pest colonization and greater winter survival as a result of climate change. Asynchrony between insect-pests and their natural enemies may upset the natural balance of biological control.
- Due to their extreme temperature, certain pesticides, such as pyrethroids, organophosphates, and bio pesticides, break down more quickly at higher temperatures. Variations in temperature can cause many of these products to lose their effectiveness in controlling pests, requiring regular applications of insecticides to maintain effective control. The development of insect resistance, pest resurgence, and secondary pest outbreaks are all greater hazards associated with this, which could exacerbate the pest problems. Ultimately it will increase production cost to the farmers (Petzoldt and Seaman, 2010).

2.3 Future Pest Risk:

Karuppaiah *et al.* (2023) conducted a study on the prediction of the potential geographical distribution of *Thrips tabaci*, or onion trips, in India using MaxEnt climate change projections. Their findings indicate that, under the current scenario, *T. tabaci* is primarily found in the central and southern states of India, with a distribution of 1.17×10^6 km^2, covering 36.4% of the country and a suitable temperature range of 22–28°C and an average annual rainfall of 300–1000 mm. Conversely, the species distribution in low-latitude regions, primarily the central and southern states of India, would decline in the setting of 2050 annual average temperature (>30.0°C) and annual average rainfall (>1000 mm) under climate change. Furthermore, the optimal suited habitat would be concentrated in a few numbers of northern Indian states where habitat suitability is already present.

The study conducted by Baradevanal *et al.* (2020) aimed at predicting the potential geographic distribution of *Apsylla cistellata*, the mango shoots gall psylla (Psyllidae: Hemiptera), in relation to the present and projected climate scenarios for 2050 and 2070. Six Indian states were included in the study because that is where their infestation and occurrence were observed. The research offered a thorough understanding of the shoot gall psylla infestation surveys conducted from 2012 to 2018. In order to model prospective shoot gall psylla distributions, existing and future climate change scenarios from the WorldClim database were obtained and the Maxent modeling technique was utilized to set with occurrence points and current climate data. The findings indicated that the distribution of shoot gall psylla was observed in the eastern half of Madhya Pradesh and the western and central parts of Uttar Pradesh under present climate change scenarios. Future climate change scenarios indicate that *A. cistellata* will mostly inhabit places in Western and Central Uttar Pradesh, as well as sections of Himachal Pradesh and Uttarakhand in the south. The study offers an abundance of information that may be used to understand possible shifts in the distribution and activity of pests in specific places as a response to both present-day and future climate change scenarios. Using a phenology modeling with GIS mapping, Kroschel *et al.* (2012) investigated the effects of changes in global temperature driven on by climate change on the distribution and abundance of the potato tuber moth *Phthorimaea operculella* (Zeller).

They employed three risk indices (The establishment, generation, and activity index) in a geographic information system (GIS) environment to map and quantify changes for climate change scenarios of the year 2050 based on downscaled climate-change data of the scenario A1B from the WorldClim database. They also used a process-based climatic phenology model for *P. operculella*. The Insect Life Cycle Modeling (ILCYM) software, which was recently developed by The International Potato Center (CIP) in Lima, Peru, was used for all applications and simulation. According to the findings, three major change scenarios were possible: (1) The potential for *P. operculella* to cause harm will gradually spread throughout all areas where the pest is now prevalent, with a disproportionate rise in warmer cropping regions found in the tropics and subtropics. Economic losses are expected to happen in areas where *P. operculella* is well-established and produces more than four generations annually. (2) An increase in its range in temperate northern hemisphere countries, with an extra 8.6% (699,680 ha), 4.2% (32,873 ha) and 2.7% (234,404 ha) of the potato producing area in Asia, North America, and Europe at higher risk and a moderate rise in its potential for damage. (3) An increase in range in hilly tropical temperate zones, accompanied by a moderate rise in potential harm.

2.4 Mitigation and Management Strategies:

A variety of strategies are used in IPM (Integrated Pest Management) mitigation and management strategies with the goal of effectively controlling pests while lowering hazards to people, the environment and non-target creatures. The need of chemical interventions can be reduced by giving priority to preventive measures including crop rotation, maintaining good sanitation, and routinely monitoring pest populations. Encouraging natural enemies, like beneficial insects or microbiological agents, to lower pest populations is a vital component of integrated pest management (IPM). This might be accomplished by introducing, enhancing, or conserving these natural enemies (Saeed Ben Youssef, 2023).

Adapting cultural practices, such as using resistant crop varieties, choosing the right planting dates and employing effective irrigation and fertilization methods, contributes to lowering pest vulnerability and enhancing overall crop well-being. The incorporation of physical barriers, like screens, nets or fences, serves as a non-chemical means to prevent pests from accessing crops or structures, offering an efficient pest control approach. Chemical pesticides are integrated into IPM only if deemed necessary. Routine monitoring and scouting for pests enable early detection and intervention, implementing predetermined action thresholds when required. Essential to successful implementation is the education of farmers, pest control professionals and the broader community about the principles and advantages of the IPM approach.

2.5 Conclusion:

In conclusion, climate change exerts a multifaceted and profound influence on insect populations. The diverse effects include alterations in population growth rates based on thermal tolerance, shifts in migration patterns and habitat ranges, disruptions in overwintering or resting periods and impacts on insect abundance and biodiversity. These changes are driven by the complex interplay between rising temperatures, extreme weather events and shifting climatic conditions. Understanding these dynamics is crucial for both ecological and agricultural systems, as insects play vital roles in pollination, pest control and ecosystem health. Addressing the impact of climate change on insects is not only an ecological imperative but also a practical necessity for food security and the preservation of biodiversity. Comprehensive research and adaptive strategies are essential to mitigate the far-reaching consequences of the changing climate on insect populations and by extension, the broader ecosystems they inhabit.

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