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Impact of climate change and pest management

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Abstract
Climate change and global warming are of great concern to overall world. Insects and plants are affected by climate change and typically susceptible to new environmental factors i.e. rise in temperatures, greenhouse effect and changes in rainfall patterns over the seasons. Each additional degree of temperature rise could cause yield losses from insect pests to increase by a further 10-25%.The relationships between plants and insects are thus changed with significant consequences for food security and natural ecosystems. They can result in an expansion of their geographic distribution, increased survival during overwintering, increased number of generations, altered synchrony between plants and pests, altered interspecific interaction, increased risk of invasion by alien pest species, increased incidence of insect-transmitted plant diseases. As a result, there is a serious risk of crop economic losses as well as a challenge to human food security. As a major driver of pest population dynamics, climate change will require adaptive management strategies to deal with the changing status of pests. Several priorities can be identified for future research on the effects of climatic changes on agricultural insect pests and pest management tactics.

Keywords: Climate effect, insect-pests, management, population dynamics, agricultural crops, outbreak

Introduction

Climate change now a day is globally acknowledged fact. It has serious impacts on diversity, distribution, incidence, reproduction, growth, development, voltisim and phenology of insect pests. Climate changes also affect the activity of plant defence and resistance, biopesticides, synthetic chemicals, invasive insect species, expression of *Bt* toxins in transgenic crops. Considering such declining production efficiency due to depleting natural resource base, serious consequences of climate change on diversity and abundance of insect-pests and the extent of crop losses, food security for 21st century is the major challenge for human kind in years to come. Being a tropical country, India is more challenged with impacts of looming climate change. In India, pest damage varies in different agro-climatic regions across the country mainly due to differential impacts of abiotic factors such as temperature, rising atmospheric CO_2 levels, humidity and rainfall. Pest insects will proliferate more as a result of rising temperatures, and temperature changes will have an impact on practically all insects. This entails the intensification of yield losses due to potential changes in crop diversity and increased incidence of insect-pests (Sharma 2025) [1].

Many of pest control methods are quite sensitive to the natural world. According to Niziolek *et al.* (2012) [2] an increase in temperatures, UV light, and relative humidity may render a large majority of these management measures ineffective. Therefore, it is important to develop effective pest management methods that will work in the future if there is a global temperature change. A potentially workable alternative to IPM is provided by host-plant resistance, bio pesticides, common enemies, and agronomic techniques (Sharma 2023) [3]. However, a considerable proportion of these control strategies' overall viability will undoubtedly change as a result of climate change (Ali *et al*., 2019) [4]. The comprehensive scientific review warns that without targeted efforts to protect insects from climate related impacts, our ability to achieve a sustainable future will be severely compromised (Meenu *et al*., 2025) [5].

Effects of Climate Change on Insect Pest

Pest outbreaks in agriculture are caused by a multitude of factors, including insect-pest biology, resource synchronization in the host plant, and natural competition among species (Letourneau 2012) [6]. The climate has a significant impact on these elements. Increases in temperature, greenhouse gases (GHGs), and precipitation brought on by global climate change will undoubtedly continue to exacerbate many insect-pest problems in cereal and other crops. Shifting, previous spring aphid excursions in Europe disruption of the multivoltine tea tortrix moth's occurrence patterns in Japan and previous appearance of the potato leafhopper over the USA, particularly in hotter years, have all been caused by changes in climatic conditions (Baker *et al*., 2015) [7]. Insects and mite pests are primarily influenced by changes in the temperature and humidity of leaf surfaces caused by stomata opening (Akram *et al*., 2019; Sharma *et al*., 2026) [8, 9]. It is challenging to forecast climate change since organisms can modify both abiotic and biotic surroundings to some extent in search of their most favoured.

Temperature

The most important abiotic element known to have a direct impact on herbivorous insects is temperature. Changes in temperature will have an impact on almost all insects to some extent, and there may be many consequences on insect life cycle. The temperature has a significant direct influence on the population dynamics of insect pests through their life histories and morphological characteristics, as well as an indirect effect through its impact on perennial plants and natural predators (Johnson and Haynes 2023) [10]. Insect life cycles will get shorter as global temperatures rise by one degree. The population of pests will increase as the life cycle shortens. Because most insects in temperate regions grow during the warmer months of the year, species whose niche space is defined by climatic regime will respond to climate change more predictably than those whose niche is restricted by other abiotic or biotic factors (Asseng *et al*., 2015) [11].

Changes in insect-Pests diversity

Insects are excellent indicators of environmental change and are crucial components of food chains, therefore diversity of insects in a habitat reveals the state of an ecosystem. India is home to 6.83% of all insect species worldwide (Baker *et al*., 2015) [7]. The relative abundance of various insect species may fluctuate due to climate change, and any species that cannot adapt to the changes may eventually become extinct. Many rare, unique, and exotic species of vibrant butterflies only exist in the Western Ghats of India (Akram *et al*., 2019) [8]. Due to the destruction of natural vegetation for various anthropogenic development activities, several butterfly species are actually in danger nowadays. All of the species that have ever existed have almost all vanished. Nearly 45 to 275 species are going extinct every day as a result of climate change, which has caused extinction rates to be 100 to 1,000 times higher than they were previously (Nasim *et al*., 2016, 2018) [12, 13].

Expansion of geographical ranges

The global distribution of insect species is largely determined by minimum temperature rather than maximum temperature; as a result, any increase in temperature will increase an insect's capacity to overwinter at higher altitudes, ultimately leading to a shift in the pest intensity from the south to the north**.** With a rise in temperature, places that are currently unfavorable due to low temperatures can start to improve (Saroj 2019) [14]. Insect pests are likely to shift the places where their host plants are grown from the tropics and subtropics to temperate regions at higher altitudes as a result of rising temperatures (Nasim *et al*., 2018)[13]. According to Diffenbaugh *et al.* (2008) [15] this may enhance the population of tropical insect species, and according to Kannan and James (2009) [16], abrupt insect pest outbreaks can completely wipe out some crop species. The population of insects that are sensitive to temperature may see a decline in relative abundance as a result of warming in temperate regions (Petzoldt and Seaman 2010) [17].

Overwintering survival and timing of the commencement spring are important at higher latitudes, leading to population build-up of, for example, global warming results altitude wise range expansion and increased overwintering survival of corn earworms *Heliothis zea* (Boddie) and *Helicoverpa armigera* (Hubner) may cause heavy yield loss and put forth major challenge for pest management in maize. Global climate change is expected to result in the range extension of migratory species like *H. armigera* (Hubner), a significant pest of cotton, pulses, and vegetables in North India (Sharma 2010; Sharma *et al*., 2010;) [18, 19]. These continuous changes in insect pest distribution and range brought on by climate change may consequently impact regional ecosystem structure, diversity, and functioning (Parry *et al*., 2007) [20].

Changes in insect phenology

Climate change has caused an ecological shift in time, with changes in species and phenology (the timing of life history phases in insects), in addition to the shift in space of species distributions. One of the simplest effects of climate change to track, it has by far the most evidence supporting it for a variety of organisms. It is anticipated that insects will move through their larval stages more quickly and mature earlier as a result of rising temperatures. As a result, potential insect reactions may include moving up the time of larval and adult emergence as well as lengthening the flying period (Menéndez 2007) [21]. The best instances of such phenological variations are seen in members of the order Lepidoptera. In the UK, where 26 of 35 species have advanced their first appearance, changes in butterfly phenology have been documented (Roy and Sparks, 2000) [22].Aphids has also been recorded to develop as adults and migrate early in the UK (Ziska 2016; Rosenblatt and Schmitz 2014) [23, 24]. Analysis of suction trap data has revealed that spring flights of the potato aphid (*Myzus persicae* (Sulzer) started two weeks earlier for every 1ºC rise in combined mean temperature of January and February.

Increased overwintering survival

Insects, which are poikilotherms, have a limited capacity to maintain homeostasis when the outside temperature changes. To support life in thermally challenging situations, they have therefore evolved a variety of responses, including behavioural avoidance through migration and physiological adaptations such diapause. Aestivation and hibernation are the two main kinds of insect diapause that let insects survive in high and low temperature environments, respectively. According to studies, global warming is more pronounced at high latitudes and happens more noticeably in the winter than in the summer (IPCC 2007) [20]. Looking at India's climate profile during the previous 100 years, warming was more obvious during the winter, and considerable rise was seen at the minimum temperature rather than the maximum so, it stands to reason that insects going through a winter diapause are likely to see the most shifts in their thermal environment (Bale and Hayward 2010) [25]. Thus, insects undergoing a winter diapause are likely to experience the most significant changes in their thermal environment (Willis *et al*. 2008) [26].

Increase in number of generations

The insects develop more quickly due to higher temperatures, there may be more generations per year. According to estimates, insects may go through one to five more life cycles per season with a 2ºC temperature increase. The population of European red mite, *Panonychus ulmi* (Koch) infesting apple in Himachal Pradesh increased with the rise in temperature with more number of generations in a season (Sharma and Bhardwaj, 2009; Bhardwaj and Sharma, 2012)[27, 28]. Warming could reduce the frequency of extreme cold occurrences, which could increase the area where insect pests can overwinter. Thus, if global temperatures rise within a favourable range, tropical and subtropical insects may develop, reproduce, and survive at faster rates. Insects will be able to produce more generations every year as a result (Petzoldt and Seaman 2010) [17].

Pest population dynamics and outbreak

As many tropical plants can withstand the phenological changes, it is anticipated that global warming may exacerbate ecological consequences like the introduction of new pests by altering phonological events like flowering times, especially in temperate plant species (Parmesan 2007) [29].With a changing climate encouraging the adoption of cultivars or crops that are insect vulnerable, invasion of novel insect-pests will be the main issue (Vyshnavi *et al*., 2023) [30]. It may result in upsetting ecological balance because of unpredictable changes in the population of insect-pests along with their existing and potential natural enemies (Parry *et al*., 2007; Rao *et al*., 2009) [20, 31].

Crop pest interaction

The tri-tropical interactions between crops, insects, and natural enemies have been shown to be affected by both bottom-up and top-down effects of the global climate change through specific physiological changes, particularly those linked to host-suitability and nutritional status. Gypsy moths have been observed attacking Red maples (*Acer rubrum* L.) and Sugar maples (*A. saccharum*), which had decreased larval weight, increased feeding time, and prolonged expansion areas on the new hosts. This may be explained by the hosts' high susceptibility or by the natural enemies' inability to find the moth larvae on unusual hosts or environment. The life cycles of some plant species may shorten due to global warming-related temperature increases which may have a significant impact on the feeding and reproduction habits of associated insect pests like aphids, jassids, mealybugs, etc. These increases have the potential to significantly worsen the detrimental ecological and economic effects (Timoney 2003) [32].

Increased prevalence of plant diseases spread by insects

Through the extension of insect vector ranges and their fast reproduction, climate change may increase the prevalence of plant diseases that are transmitted by insects (Petzoldt and Seaman 2010; Sharma 2010) [17-18].Due to the early colonization of virus-carrying aphids, the primary vectors for potato viruses in Northern Europe, higher temperatures have been found to enhance the frequency of viral illnesses in potato, particularly in early season (Robert *et al*., 2000) [33].

Carbon Dioxide

Increasing CO_2 Levels

The impact of rising CO_2 concentrations on plants is one of the most researched aspects of climate change. Herbivore responses to the rising carbon to nitrogen ratio are anticipated to include compensatory feeding, an increase in plant defense compounds, and pest species competition. Insects may increase their food consumption to make up for the nitrogen content of the leaves that has decreased (Shaw and Osborne 2011) [34]. However, different plant species react differently to elevated CO_2. Increased carbon to nitrogen ratios in plant tissue may impede the growth of insects and lengthen the life stages that are susceptible to parasitoid assault. According to research by O'Neill *et al.* (2008) [35], Japanese beetles, *Popillia japonica*, a significant pest of soybean (*Glycine max*), live longer when fed on foliage that has grown under elevated CO_2 levels.

Additionally, compared to females fed on foliage produced in a typical environment, those fed on such foliage deposited around twice as many eggs. The Japanese beetle, *P. japonica*, is thought to prefer to feed on soybean foliage grown under higher CO_2 levels because they contain higher concentrations of sugars like glucose, sucrose, and fructose. The pine sawfly, *Neodiprion lecontei*, demonstrated an increase in the efficiency of nitrogen use when grown on plants treated with high CO_2 concentration. Phytophagous insects may also develop adaptations to overcome greater carbon to nitrogen ratios. However, it appears that other insect species are unable to boost plant nutrient use efficiency to make up for the reduced nutritional quality of the plants.

Precipitation

Both the distribution and regularity of rainfall may directly and indirectly influence the prevalence of pests. Aphids, jassids, whiteflies, mites, and other minor pests may be less common on crops as they are washed away by the torrential rains (Pathak *et al*., 2012) [36]. Higher July-August rainfall declined the infestation of Two-spotted spider mite, *Tetranychus urticae* Koch in strawberry according to research on rainfall variations throughout the monsoon and resulted in the outbreak of mite attack in dry months of April-May and October-November (Sharma and Bhardwaj, 2004; Bhardwaj *et al*., 2006; Sharma 2022) [37-39]. In certain areas, it is expected that rainfall totals will decline, and the frequency of summer droughts would probably rise. Different species of root herbivore reacted differently to changes in summer rainfall. The population of molluscs is high during rainy season causing serious problems in cultivated and non-cultivated areas in high hill regions (Sharma *et al.*, 2025) [40]. The abundance of the main root-chewing species, *A. lineatus*, increased with increased rainfall, whereas Coccoidea *Lecanopsis formicarum* was unaffected by the changes in rainfall (Karuppaiah and Sujayanad 2012) [41]. *Spodoptera litura* is more common in crops including groundnut, cotton, chilies, and coriander that are grown before, after, or alongside tobacco. Its outbreak was further aided by resistance to insecticides and favourable weather, such as cyclonic weather and heavy rain followed by a dry spell.

Effect on Pollinators

Insects are essential for a variety of ecosystem services. They are superb pollinators for many of the economically significant crops (Kumari *et al*., 2024; Sharma *et al*., 2024) [42, 43]. Bees pollinate over 73% of the world's cultivated crops, followed by flies (19%), bats (6.5%), wasps (5%), beetles (5%), birds (4%) and butterflies and moths (4%), who together account for the remaining 4%. In return, the pollinators gain from acquiring floral nutrients like nectar, pollen, or both. This mutualism has developed over many years and has benefited both natural terrestrial ecosystems and agro-ecosystems that humans have created.

Impact of Climate Change on the Pest Management Strategies

a. Breakdown of host plant resistance

One of the most environmentally benign strategies for controlling damaging insect pests of crops is host plant resistance. Through a variety of processes, including antixenosis, antibiosis, and tolerance, the plant can minimize the harm caused by insect pests. The interactions between insect pests and their host plants may change as a result of changes in various environmental conditions (Sharma *et al.*, 2005; Sharma and Chauhan, 2024; Sharma *et al*., 2026) [44, 45, 46]. Stress weakens a plant's natural defences, making it more vulnerable to insect pest attack. This leads to pest outbreaks and increased crop damage. Tropical nations like India may experience substantial production loss in sorghum due to a breakdown in resistance to the midge *Stenodiplosis sorghicola* (Coq.) and the spotted stem borer, *Chilo partellus* Swinhoe, as a result of rising global temperatures and increased water stress (Sharma *et al*., 2005) [44].Increased CO_2 levels will promote plant development, but they could also make some phytophagous insects more destructive. Numerous species of herbivorous insects may encounter less nutrient-rich host plants in the 21st century's enriched CO_2 atmosphere, which will result in longer larval development durations and higher mortality rates.

Gene-modified plants

Insect resistant transgenics expressing the *Bacillus thuringiensis* (Berliner) (Bt) insecticidal protein (delta-endotoxin) were developed in a recent improvement in integrated pest management However, at times of high temperature, rising CO_2 levels, or drought, these transgenic plants demonstrated a decline in the quantity of toxin protein, which resulted in decreased resistance to insect pests (Chakraborty and Newton 2011; Choudhury *et al*., 2025) [47,48]. High temperatures in Texas, USA, caused the cotton bollworm *Heliothis virescens* (F.) to decimate Bt. cotton crops. In Australia, due to decreased Bt. toxin production in the transgenic crops, *H. armigera* and *H. punctigera* harmed Bt.-cotton in the second half of the growing season. In the later stages of crop growth, the crop was more susceptible to bollworms because Cry1Ac levels decline with plant aging. Possible reasons for insect control failure include insufficient toxin protein production, the environment's influence on transgenic expression, locally resistant insect populations, and the emergence of resistance as a result of insufficient management. Understanding how climate change affects the effectiveness of transgenic plants for pest control is crucial.

Natural Enemies

The status of individual pest species will fluctuate due to changes in the relationships between insect pests and their natural enemies as a result of global warming. The timing of various insect species' diurnal activity patterns will also change as a result of temperature changes and changes in interspecific interactions may also affect how well natural enemies control pests (Bhardwaj *et al*., 2009, 2010) [49, 50]. The majority of insects are not harmful to agro-ecosystems, and there is strong evidence that this is because of interactions between insect pests and their natural enemies, pathogens, parasites, and predators that regulate population growth (Eigenbrode *et al*., 2015) [51]. Aphid abundance increases with an increase in CO_2 and temperature, however, the parasitism rates remain unchanged in elevated CO_2.

Using insect pest control to lessen the effects of climate change

Since then, it has been stated that IPM has taken the lead as the prevailing worldview for yield insurance (Parsa *et al*., 2014) [52]. The goal of effective IPM is to impart a wide range of corresponding strategies for insect, weed, and illness management. According to one definition, IPM is a "choice-based procedure for organizing different strategies for control of all classes of pest in a naturally and financially stable manner." This broad range of options takes into account various conceptions of IPM (Gadanakis *et al*., 2015) [53].

Major principles of insect pest management

- **Breeding climate-resistant strains**

Breeding novel varieties with increased tolerance to abiotic and biotic challenges will be essential to reducing the effects of climate change and other environmental changes. There is a risk that the growth seasons for some Rabi/cold season crops will be delayed and/or shortened due to the winter's later onset and/or shorter length. Therefore, we should focus on breeding types that are ideal for late planting and can withstand challenging climatic circumstances as well as outbreaks of pests and diseases (Ali *et al*., 2014) [54].

- **Adjusting crop calendars**

Reduced crop growth seasons and severe issues with early insect infestations may be the result of rising global temperatures and changing rainfall patterns. As a result, with a changing climate, certain traditional cultural practices—like crop rotation and planting dates—will be less or ineffective at controlling crop pests. Therefore, it is necessary to adjust the crop calendars in line with the shifting crop environment. The extent of crop losses and predicted changes in pest incidence must be taken into account by crop growers when they adjust their insect management tactics.

- **Crop Pest Risk Mapping Using GIS**

It is recommended to use Geographic Information Systems (GIS) in area-wide pest management programs because they enable entomologists to relate insect-pest outbreaks to biographical and physiographical characteristics of the terrain. Through the use of GIS, it is possible to study how climatic changes will impact the development, occurrence, and population dynamics of insect-pests by forecasting and mapping trends of potential changes in geographical distribution (Sharma *et al*., 2010) [19] and by identifying agro-ecological hotspots and potential pest risk areas.

Practices of Modified Integrated Pest Management (IPM)

The focus of plant protection in the context of sustainable agriculture is on preventative or indirect methods, which must be completely utilized before control or direct measures are used. The most recent tools, like forecasting techniques and thresholds that have been verified by science, must be used to make decisions about the necessity of control measures. When indirect techniques are unable to prevent economically unbearable losses, direct pest control tools are the last alternative. The FAO suggests a twofold strategy that involves both global and regional action and, most importantly, a sizable investment in enhancing current early detection and control mechanisms. To stop the spread, new agricultural techniques must be developed, new crop species must be introduced, and integrated pest control methods must be used. To address the significant effects of global warming, however, it has been anticipated recently that researchers and producers will need to modify many of these carefully designed IPM strategies (Istatu *et al*. 2025) [55].

Recommendations for crop protection are affected by environmental factors including drought stress. The economic threshold can readily be lowered when a crop is under drought stress because it is less able to handle the additional stress brought on by herbivorous insects. Because insects grow more quickly at rising temperatures, populations grow more quickly and crop damage happens sooner than currently anticipated. To lessen the effects of agricultural pests on crops in a changing environment, modified farming practices and adaptive management strategies are required. To reduce vulnerability to pest outbreaks, these could include (I) planting several crop kinds; (II) planting at various times of the year; and (III) enhancing biodiversity at field edges to enhance the number of natural enemies. Insects employ pheromones and allele chemicals to perceive their surroundings, which is a crucial process. They have a significant impact on a number of IPM strategies, including monitoring, trapping, push-pull tactics, biological control, and mating disruption. The novel pest control techniques and potential insecticide formulations, as well as attractants and repellents, should be the main focus.

Climate Forecasting and Model Development

Climate models can be a useful tool for predicting the range of potential changes on a global scale when combined with the environmental needs of a specific pest species. Therefore, the ability to forecast the results of an insect infestation can be improved by modelling the pest risk along with the responses of its plant hosts to climate change (Sharma *et al*., 2017; Sharma, 2026) [56,57]. Ecological niche models (ENMs) are used to primarily assess the probable range of insect pest species. They fall into two categories: mechanistic models and correlative models. Correlative models forecast possible suitable locations for the specific species based on correlated values of environmental variables and records of occurrence. For predicting future changes in the geographic distribution of species, evaluating extinction rates, and establishing priorities for biodiversity conservation, correlative modelling is a widely used method. These models determine statistical correlations between a species' existing geographic distribution and climate characteristics, which are then applied to climate change forecasts to suggest future habitats for that species.

Conclusion

Climate change plays a significant role in determining species distribution and abundance. Extreme weather events and the direct impact of anthropogenic climate change pose a possible threat to the global ecology, agricultural output and production. Many insects have huge populations and rapid generation rates, and they may adapt quickly to climatic change in terms of phenology, fecundity, survival, selection, and habitat utilization. Insect abundance and distribution may alter quickly as a result of these changes to their life histories. Dealing with the climate change is really tedious task owing to its complexity, uncertainty, unpredictability and differential impacts over time and place. Understanding abiotic stress responses in crop plants, insect-pests and their natural enemies is an important and challenge ahead in agricultural research. Impacts of climate change on crop production mediated through changes in populations of serious insect-pests need to give careful attention for planning and devising adaptation and mitigation strategies for future pest management programmes. Climate change is also intensifying the damage insects inflict on crops, leading to greater yield losses and posing significant challenges for pest management. Therefore, there is a need to have a concerted look at the likely effects of climate change on crop protection, and devise appropriate measures to mitigate the effects of climate change on food security.

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