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EFFECT OF CLIMATE CHANGE ON INSECT PESTS AND MANAGEMENT ADAPTATIONS: REVIEW

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Abstract: *Climate and weather can substantially influence the development and distribution of insects. Changes in climate may result in changes in geographical distribution, increased over wintering, changes in population growth rates, increases in the number of generations, extension of the development season, changes in crop-pest synchrony, changes in inter specific interactions and increased risk of invasion by migrant pests. This may affect perilously the agricultural production and the livelihood of farmers especially in tropical and subtropical countries where larger proportion of work force is directly depending on climate sensitive sectors such as agriculture. In this article, we enlighten through the extensive literature survey, the climate change induced challenges that the crop growers have to face in near future in managing harmful insect pests of their crops along with its socio-economic impacts on farming community and also how the pest management practices should be applied to manage pest problems.*

Key words: *Climate, weather, insect, pests management*

Introduction: The Intergovernmental Panel on Climate Change (IPCC)[1] predicts an increase in the mean global temperature of 1.4^{o} to 5.8^{o}C by the end of twenty-first century[2].Climate change is also projected to cause more frequent and intense ElNino-Southern Oscillation (ENSO) events leading to widespread drought in some area and extensive flooding in other[3].Consequently, such events will have negative impacts on the availability of water resources, food and agricultural security, human health and biodiversity. These changes in climatic condition are also predicted to profoundly influence the population dynamics and the status of agricultural insect pests[4-6] as temperature has strong and direct influence on insect development, reproduction and survival[6].Over the past 30 year or so, changing climate and in particular global warming has already produced numerous shift in the distribution and abundance of species[7-8].Climate change and invasive species are considered as two of the most important ecological issues facing the world today[9].Understanding and managing the effects on agricultural pests and diseases are major challenges. As a world-wide average, the potential crop yield loss to animal pests and pathogens has been estimated at 18% and 16%, respectively[10].In livestock total losses to trypanosomosis alone are estimated at US$1.3-5 billion[11].Thus, effective management of pests and pathogens is key for making efficient use of natural resources, maintaining income and assets for farmers by reducing losses and keeping food prices affordable enough to maintain food security. The best form of management is often use of diseases and pests resistant varieties or breeds, where development of a new crop variety typically requires a decade and development of new livestock breeds is much slower; benefits of research may take 40 years to be realized[12,13].where inadequate or no sources of resistance have been found in established crop germplasm, other forms of crop protection are needed to keep pests under control. The development and implementation of new integrated pest management (IPM) strategies are time consuming and the resulting time lag in response to pest and disease problems is one motivation for understanding how climate change will influence pest and disease risk. Several biological features of pests and diseases increase the challenges of predicting the effects of climate change, including the potential for more frequent weather extremes to have particularly strong effects[14,15].Crop plants used as a food by human beings are damaged by over 10,000 species of insects, and cause an estimated annual loss of 13.6% globally[16] and 23.3% in India[17]. In India, the average annual losses have been estimated to be 17.5% valued at US$17.28 billion in eight major field crops (cotton, rice, maize, sugarcane, rapeseed-mustard, groundnut, pulses, coarse cereals, and wheat)[18]. Losses due to insect damage are likely to increase as a result of changes in crop diversity and increased incidence of insect pests due to global warming. Current estimates of changes in climate indicate an increase in global mean annual temperatures of 1^{o}C by 2025, and 3^{o}C by the end of the next century. The date at which an equivalent doubling of CO2 will be attained is estimated to be between 2025 and 2070, depending on the level of emission of greenhouse gasses[19,20].Mean annual temperature changes between 3^{o}C and 6^{o}C are estimated to occur across Europe, with greatest increases occurring at high latitudes. Increased temperatures have drastically affected the rice production due to decrease crop duration in Philippines (10% reduction in yield in rice per 1°C rise in temperature)[21]. An increase of 6^{o}C in temperature, and precipitation deficit of 300 nm reduced the maize yield by 36% in the European Union[22].Host-plant resistance, bio-pesticides, natural enemies, and synthetic chemicals are some of the potential options for integrated pest management. However, the relative efficacy of many of these pest control measures is likely to change as a result of global warming. Changes in precipitation are of greater importance for agriculture than temperature changes, especially in regions where lack of rainfall may be a limiting factor for crop production[23]. Global mean annual precipitation may increase as a result of intensification of the hydrological cycle[24], which will cause disruption of agriculture as the cropping systems and the composition of fauna and flora will undergo a gradual change[4,25]. High mobility and rapid population growth will increase the extent of losses due to insect pests.

Effects on Insect-pests: Geographical distribution of insect pests confined to tropical and subtropical regions will extend to temperate regions along with a shift in the areas of production of their host plants, while distribution and relative abundance of some insect species vulnerable to high temperatures in the temperate regions may decrease as a result of global warming. These species may find suitable alternative habitats at greater latitudes. Many species may have their diapause strategies disrupted as the linkages between temperature and moisture regimes, and the day length will be altered. Genetic variation and multi-factor inheritance of innate recognition of environmental signals may mean that many insect species will have to adapt readily to such disruption. Climate change will also result in increased problems with insect transmitted diseases. These changes will have major implications for crop protection and food security, particularly in the developing countries, where the need to increase and sustain food production is most urgent. Long-term monitoring of population levels and insect behavior, particularly in identifiably sensitive regions, may provide some of the first indications of a biological response to climate change. In addition, it will also be important to keep ahead of undesirable pest adaptations, and therefore, it is important to carefully consider global warming and climate change for planning research and development efforts for pest management and food security in future.

Incidence of pest and diseases is most severe in tropical regions due to favorable climate/weather conditions, multiple cropping and availability of alternate pests throughout the year. Therefore, in the south Asia, pests and diseases deleteriously affecting the crop yields are prevalent. Climate factors are the causative agents in determining the population fluctuations of pests. They influence plant disease establishment, progression and severity. In fact, a clear understanding of population dynamics, as influenced by abiotic and biotic parameters of environment, is of much help in pest forecasting and to formulate control measures. The global warming may affect growth and development of all organisms including insect-pests themselves. Among all the abiotic factors, temperature is the most important one affecting insect distribution and abundance in time and space, since these are cold-blooded animals. The insects cannot regulate their body temperature and thereby, ambient temperature influences their survival, growth, development and reproduction. The swarms of locust produced in the Middle East usually fly eastward into Pakistan and India during summer season and they lay eggs during monsoon period.

The swarms as a result of this breeding, return during autumn to the area of winter rainfall, flying to all parts of India and influencing *kharif* crops[26]. Changes in rainfall, temperature and wind speed may influence the migratory behavior of locust. Forecasting of aphids (*Lipaphis erysimi* Kalt) on mustard crop, grown during winter season in northern part of India based on the movement of western disturbances, has been established[27].Western disturbances bring in cold and humid air from the Mediterranean region, resulting in cloudy and favourable weather conditions for occurrence of aphids on mustard crop. It was observed that there was a sharp increase in the population of aphids when the mean daily temperature ranged from 10 to14◦C with relative humidity of 67 - 85% and cloudiness. For every insect species, there is a range of temperature within which it remains active from egg to adult stage. Lower value of this range is called threshold of development or developmental zero. Within favourable range, there is an optimum temperature where most of the individual of a species complete their development. Exposure to temperature on either side exerts an adverse impact on the insect by slowing down the speed of development[28].The studies have shown that insects remain active within temperature range from15 to 32◦C[29]. In case of red cotton bug, at constant temperature of 20, 25 and 30◦C, the average duration of life cycle was found to be 61.3,38.3 and 37.6 days, respectively, while at 12.5 and 35◦C, the pest did not show any development[30].A maximum temperature ranging from19 to 24◦C with a mean of 12–15◦C for mustard aphid, *Lipaphis erysimi*; maximum temperature between 26.9 and 28.2◦C with a relative humidity of 80.6–82.1%for rice stinkbug; temperature from 20 to 28◦C for rice green leafhopper, temperature from 24.8 to 28.6◦C for brown plant hopper; mean temperature around 27.5–28.5◦C for aphids, thrips and leaf weevil on green gram and maximum temperature from 23 to 27.8◦C for gram pod borer, have been found most congenial for their development[29]. With the increase in temperature, the rate of development of insects may also increase, if temperature still lies within the optimal range for the pests. As a consequence, they could complete more number of generations for inflicting more loss to our crops. Crop-pest interaction needs to be evaluated in relation to climate change in order to assess the crop losses. Development of diseases and pests is strongly dependent upon the temperature and humidity. Any change in them, depending upon their base value, they can significantly alter the scenario, which ultimately may result in yield loss. Any small change in temperature can result in changed virulence as well as appearance of new pests in a region. Likewise, crop-weed competition may be affected, depending upon their growth behaviour. With an increase in concentration of carbon dioxide, the nutritional status of crop will change, and the net effect on agricultural production will depend upon interaction between pests and crops. Gradual climate warming will lead to changes in the composition of pest fauna in different areas. The high population growth rate of many species will ensure changes in pest distribution. If the rise in winter temperature takes place, the duration of hibernation of pests may decrease, thus increasing their activity. Uncongenial areas for pests due to low temperature at present may become suitable due to rise in temperature. However, we should not forget that insects could adapt to slow changes in the environment and with increase in temperature, their favorable range of temperature may also shift.

The following scenarios can be visualized regarding impact of climate change on pest dynamics in agriculture

- Extension of geographical range of insect pests,
- Increase in number of generation
- Increased risk of invasion by migrant pests,
- Impact on arthropod diversity, out breaks and extinction of species,
- Changes in insect – host plant interactions,
- Increased incidence of insect vectored plant diseases
- Increased over-wintering and rapid population growth,
- Changes in synchrony between insect pests and their crop hosts,
- Introduction of alternative hosts as green bridges, and
- Reduced effectiveness of crop protection technologies

Expansion of Geographic Ranges: The geographic distribution and abundance of plants and animals in nature is determined by species specific climate requirements essential for their growth, survival and reproduction. Altered temperature and rainfall regimes with the predictable changes in climate will determine the future distribution, survival and reproduction of the species[31].

With rise in temperature, the insect-pests are expected to extend their geographic range from tropics and subtropics to temperate regions at higher altitudes along with shifts in cultivation areas of their host plants[32]. This may lead to increased abundance of tropical insect species and sudden outbreaks of insect-pests can wipe out certain crop species, entirely. At the same time; warming in temperate region may lead to decrease in relative abundance of temperature sensitive insect population. Mostly the Polar Regions are constrained from the insect outbreaks due to low temperature and frequently occurring frosts. In future, projected climate warming and increased drought incidence is expected to cause more frequent insect outbreaks in temperate regions also.

Global warming resultant altitudes wise range expansion and increased over wintering 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, a staple food crop of USA[33]. Range extension in migratory species like *Helicoverpa armigera* (Hubner), a major pest of cotton, pulses and vegetables in North India is predicted with global climate warming[34]. Subsequently, these ongoing shifts in insect-pest distribution and range due to changing climate may alter regional structure, diversity and functioning of ecosystems.

Increase in Number of Generations: As temperature being the single most important regulating factor for insects. Global increase in temperature within certain favourable range may accelerate the rates of development, reproduction and survival in tropical and subtropical insects. Consequently, insects will be capable of completing more number of generations per year and ultimately it will result in more crop damage.

Risk of Introducing Invasive Alien Species: According to the Convention on Biological Diversity (CBD), invasive alien species are the greatest threat to loss of biodiversity in the world and impose high costs to agriculture, forestry and aquatic ecosystems by altering their regional structure, diversity and functioning[35].

It is expected that global warming may exacerbate ecological consequences like introduction of new pests by altering phenological events like flowering times especially in temperate plant species[36] as several tropical plants can withstand the phenological changes. Invasion of new insect-pests will be the major problem with changing climate favouring the introduction of insect susceptible cultivars or crops[37].

Impact on Pest Population Dynamics and Outbreaks: Changes in climatic variables have led to increased frequency and intensity of outbreaks of insect-pests. 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[38]. Outbreak of sugarcane woolly aphid *Ceratovacuna lanigera* Zehntner in sugarcane belt of Karnataka and Maharashtra states during 2002-03 resulted in 30% yield losses. These situations of increased and frequent pest damage to the crops have made another big hole in the pockets of already distressed farmers by increasing the cost of plant protection and reducing the margin of profit.

Breakdown of Host Plant Resistance: Expression of the host plant resistance is greatly influenced by environmental factors like temperature, sunlight, soil moisture, air pollution, etc. Under stressful environment, plant becomes more susceptible to attack by insect-pests because of weakening of their own defensive system resulting in pest outbreaks and more crop damage[39]. Thermal and drought stress associated breakdown of plant resistance have been widely reported[40]. With global temperature rise and increased water stress, tropical countries like India may face the problem of severe yield loss in sorghum due to breakdown of resistance against midge *Stenodiplosis sorghicola*(Coq.) and spotted stem borer *Chilo partellus* Swinhoe[32].

The environmental factors like high temperature have been found affecting transgene expression in Bt cotton resulting in reduced production of Bt toxins, this lead to enhanced susceptibility of the crops to insect-pests like bollworms viz., *Heliothis virescens* (F.)[41], *Helicoverpa armigera* (Hubner) and *Helicoverpa punctigera* (Wallen).

Increased Incidence of Insect Vectored Plant Diseases: Climate change may lead to more incidence of insect transmitted plant diseases through range expansion and rapid multiplication of insect vectors[42,32,35]. Increased temperatures, particularly in early season, have been reported to increase the incidence of viral diseases in potato due to early colonization of virus-bearing aphids, the major vectors for potato viruses in Northern Europe[43].

Pest Management Adaptations: The relationship between crop protection costs and the resulting benefits will change as a result of global warming and climate change. This will have a major bearing on economic thresholds, as greater variability in climate will result in variable impact of pest damage on crop yields. Increased temperatures and UV radiation, and low relative humidity may render many of these control tactics to be less effective, and therefore, there is a need to:

- Predict and map trends of potential changes in geographical distribution, and study how climatic changes will affect development, incidence, and population dynamics of insect pests.
- Understand the influence of global warming and climate change on species diversity and cropping patterns, and their influence on the abundance of insect pests and their natural enemies.
- Understand the changes in expression of resistance to insect pests, and identify stable sources of resistance, and pyramid the resistance genes in commercial cultivars.
- Study the effect of global warming on the efficacy of transgenic crops in pest management.
- Assess the efficacy of various pest management technologies under diverse environmental conditions and develop appropriate strategies for pest management to mitigate the effects of climate change.
- Awareness regarding impacts of climate change and adoption of mitigation and adaptation measures
- Developing early warning systems/decision support systems
- Sensitization of stakeholders about climate change and its impacts
- Farmers' participatory research for enhancing adaptive capacity
- Promotion of resource conservation technologies

In addition to the strategies discussed above, we need to decide the future line of research for combating the pest problems under climate change regimes.

Alternation in Sowing Dates of Crops: Global climate change would cause alternation in sowing dates of crops which alter host-pest synchrony. There is need to explore changes in host plant interaction under early, normal and late sown conditions in order recommended optimum sowing dates for reduced pest pressure and increased yield

Breeding Climate-Resilient Varieties: To minimize the impacts of climate and other environmental changes, it will be crucial to breed new varieties for improved resistance to abiotic and biotic stresses. Considering late onset and/ or shorter duration of winter, there is chance of delaying and shortening the growing seasons for certain Rabi/ cold season crops. Hence we should concentrate on breeding varieties suitable for late planting and those can sustain adverse climatic conditions and pest and disease incidences.

Rescheduling of Crop Calendars: As such certain effective cultural practices like crop rotation and planting dates will be less or no effective in controlling crop pests with changed climate. Hence there is need to change the crop calendars according to the changing crop environment. The growers of the crops have to change insect management strategies in accordance with the projected changes in pest incidence and extent of crop losses in view of the changing climate.

GIS Based Risk Mapping of Crop Pests: Geographic Information System (GIS) is an enabling technology for entomologists, which help in relating insect-pest outbreaks to biographic and physiographic features of the landscape, hence can best be utilized in area wide pest management programmes. How climatic changes will affect development, incidence, and population dynamics of insect-pests can be studied through GIS by predicting and mapping trends of potential changes in geographical distribution[35] and delineation of agro-ecological hotspots and future areas of pest risk[44].

Screening of Pesticides with Novel Mode of Actions: It has been reported by some researchers that the application of neo-nicotinoid insecticides for controlling sucking pests induces salicylic acid associated plant defense responses which enhance plant vigour and abiotic stress tolerance, independent of their insecticidal action[45]. This gives an insight into investigating role of insecticides in enhancing stress tolerance in plants. Such more compounds needs to be identified for use in future crop pest management.

Evolve temperature tolerance strains of natural enemies

Weather and pest forecasting

Conclusion: Climate change now a day is globally acknowledged fact. 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. If pest damage to crops does increase it will result in significant economic losses.In India, pest damage varies in different agro-climatic regions across the country mainly due to differential impacts of abiotic factors such as temperature, humidity and rainfall. More work is required to identify the effects of weather and climate on important agricultural pests, and determine the climatic variables to which different species are most sensitive. An improved understanding of the interactive relationships between pests, their hosts and climate will contribute greatly to the development of crop-pest models which could be used in these regions.

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