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Effect of climate change on insect pests of fruit crops and adaptation and mitigation strategies: A review

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Abstract

Climate Change is possibly the most significant global change that has attracted the attention of scientific communities globally. Climate induced changes in pest activity which further affects agricultural production. Anthropogenically induced climate change arising from increasing levels of greenhouse gases in atmosphere would likely to have a significant effect on agricultural pests. Changes in climate may trigger major changes in geographical distribution of insect pests, insect population dynamics, survival of insect pests, herbivore-plant interaction, activity and abundance of natural enemies and efficacy of crop protection technologies. Increased pest population will stress crop plants results in higher crop loss, reduce yield and quality of produce. Insects are poikilothermic in nature and therefore they are highly sensitive to their surrounding climate particularly the temperature. Due to climate change, there is an increase in number of pest population, outbreaks of pests and increased number of generations per year. This would definitely increase the damage caused by insects, decrease crop yield, increase the cost on crop protection and thereby affect the economy. Therefore, there is a need to generate information on the likely effects of climate change on insect pests to develop robust technologies that will be effective and economical in the future under global warming and climate change.

Keywords: Climate change, anthropogenically, greenhouse gases, insect pests

Introduction

The most important as well as the most complex environmental issue is global climate change. According to IPCC (Intergovernmental panel on climate change), it is defined as “change in climate over time, whether due to natural variability or as a result of human activity”. The IPCC during its fifth assessment report [1] mentioned globally averaged combined land and ocean surface warming of 0.85 ^{0}C during the period from 1880 to 2012. There is a large increase in concentration of greenhouse gases in atmosphere after pre industrialization period mainly due to human activities. The per cent increase of 47.14 %, 156.2 %, 22.96 %, 42.19 % was observed in gases i.e. carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2) and tropospheric ozone respectively [2]. Such changes in climate and weather could affect the status of insect pests of crops. These may arise not only as result of direct effects (on the distribution and abundance of pest population) but also as a result of indirect effects (on the pests host plants, competitors and natural enemies) [3]. Some pests which are already present but at low densities may also be able to exploit the changing conditions by spreading more widely and reaching densities above threshold level [3, 4].

Climate change (especially rise in temperature and atmospheric carbon dioxide concentration), is a major issue today. The carbon dioxide concentration may rise upto 550 ppm by as early as 2035 [5]. Climate change strongly influence the geographical distribution of insect pests, which is more determined by low temperatures than that of higher temperatures [6-11]. The effect of climate change on insect pests can be both direct as well as indirect effects. This might affect the growth of leaf eating insects through altered consumption and digestibility [12]. Temperature has a direct effect on insects as it imparts the developmental time, longevity and fecundity, on the other hand elevated CO_2 has an indirect host-mediated effect on growth and development of insect pests [13, 14]. The plants grown under enriched CO_2 conditions, provides a nutritionally depleted food for herbivores, due to reduction in leaf nitrogen content [15]. Because leaf nitrogen is considered essential for growth and reproduction of insects [16]. Therefore, reduction in leaf nitrogen content in the plants grown under elevated CO_2conditionsmay elicit strong responses from them.

How do insects respond to Climate Change

The change in climatic conditions have a strong influence on the development, reproduction and survival of insect pests as well as their natural enemies [8]. Insects respond more frequently to climate change than plants and vertebrates, due to their poikilothermic nature and also due to their short generation time and high reproductive rates. Potential responses will include changes in phenological patterns, habitat selection and expansion, and/or contraction of geographic distribution. Species responses are expected to be unique, depending on their characteristics, growth rates and diapause requirements that may influence species distribution and population increase. [8] Fast growing, nondiapausing species will respond to warming by expanding their distributions, whereas slow growing species, will suffer range contractions. The mostly observed responses includes early adult emergence and an increase in the length of the flight period. Changes in butterfly phenology has been reported in Europe [5, 17], and species have advanced their flight periods by 2-10 days for every 1 ^{0}C increase in temperature. In Spain, butterflies appeared 1-7 weeks earlier by during past 15 years, and by 8 days per decade in California [18]. Several species of microlepidoptera have also shown temporal shifts in their phenology in Europe [19]. Early adult emergence and early arrival of migratory aphids have been observed in the United Kingdom [20]. A common phenological responses has been observed in four unrelated species of insects (a butterfly, a bee, a fly, and a beetle) [21].

Further, global warming and changes in climate will influence:

- Activity and abundance of insect pests.
- Geographical distribution of insects-pests.
- Overwintering, development and population dynamics.
- Expression of host-plant resistance to insects.
- Pest outbreaks and invasion of pest.
- Interaction between plants and insect pollinators.
- Effectiveness of crop production technologies.

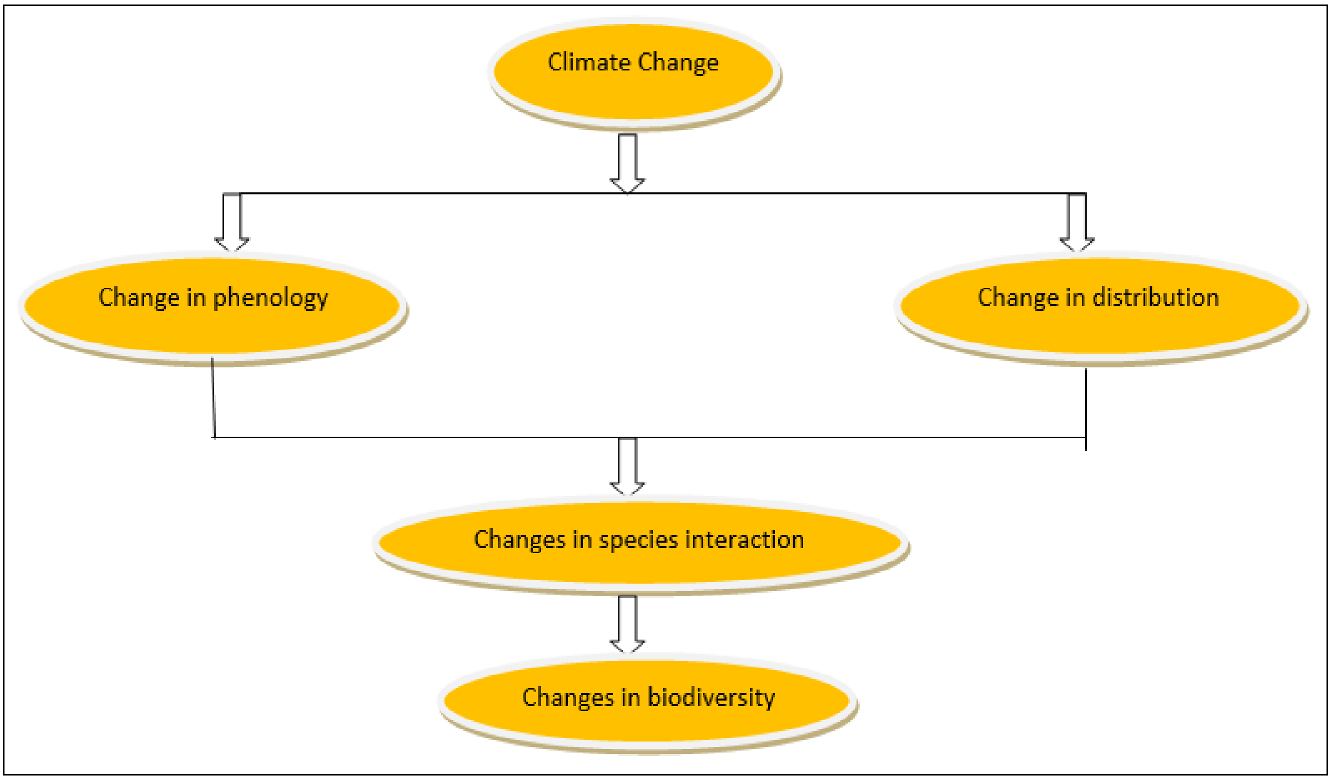

Fig 1: Response of insect pests to climate change

Effect of temperature on insect pests of fruit crops:

Insects are cold blooded organisms i.e. their body temperature is approximately the same as that of environment. Therefore, temperature is considered as one of the most important environmental factor that influence insect behaviour, development as well as reproduction. Researchers have shown that increased temperature can profoundly affect insect survival, development, geographic range and population size. Temperature can also affect insect physiology and development directly or indirectly through the physiology or existence of hosts. Every species has a particular threshold of temperature above which development occurs and below which the development ceases. Species diversity per unit area in insects tends to decrease with higher latitude and altitude [22, 23], i.e. the rising temperature could result in more insect species attacking more hosts in temperate climates [8]. The increase in temperature will further leads to:

Increasing

Northward migration
Migration upto elevation gradient
Insect development rate and oviposition
Potential for insect outbreak
Invasive species introduction
Insect extinction

Decreasing

Effectiveness of biocontrol agents
Reliability of economic threshold level
Insect diversity
Rate of Parasitism

Development and survival: The host physiology and its resistance mechanism are likely to be temperature sensitive which may be altered by increase in temperature i.e. stress conditions make the host plants more susceptible and therefore lowered its defense mechanism. Earlier apple orchards of Himachal Pradesh, India were found to be free from the attack of phytophagous mite, thereafter the attack of European red mite, *Panonychus ulmi* was found in an apple orchard in Kullu during 1992. Later on, this infestation spread to other districts like Shimla, Mandi and Kullu and become a regular pest of Apple [24]. Some studies revealed that every species has a threshold temperature above which - development occurs and below which - development ceases. As an example, the optimum temperature range for development, survival and reproduction of Papaya mealy bug (*Paracoccus marginatus)* is 18-30 ^{0}C [25]. Maximum survival rate of Guava fruit fly (*Bactrocera correcta*) is within a temperature range of 24-33 ^{0}C and its survival decreased at higher or lower temperatures [26]. Some researchers studied the development and survival of different life stages of *Bactrocera zonata* at different temperature and observed that the development times significantly decreased over a range of 15-30 ^{0}C for eggs and pupal stages of *Bactrocera zonata* but above this temperature development time decreases [27]. It is meant to be a fact that with an increase in 2 ^{0}C temperature, insects might experience one to five more generations per year [28]. Insects that spend most of its life stages in the soil may be more gradually affected by changes in temperature than those that spend most of the time above ground because soil provides an insulating medium that will tend to buffer temperature changes more than air [8].

Migration: The onset of flight as well as extent of dispersal are the two essential parameters that affect the mating timing, host finding and colonization and brood establishment in insects. There is a temperature threshold set for insect flight which may vary both among and within species, with season and also with region. In order to balance the effects of climate change, Meloids and chrysomelids can migrate up hills to prevent exposure to the unsuitable temperature and then increase their spread. Further, emergence as well as the first appearance of insects after hibernation may also depends on day length and temperature thresholds. Studies on aphids and moths have shown that increasing temperatures can allow insects to reach their minimum flight temperature sooner, resulting in increased dispersal capabilities [20]. *Bactrocera zonata* is only restricted to north India till late 1990's. But later it has been observed during winters in U.P because of increase in soil temperature due to climatic changes.

Range Expansion of insect pest due to climate change

Under unfavourable conditions in the local/ regional climate i.e. rise in temperature, carbon dioxide and humidity, there will be altitude wise shift in insect pests along with their host plants which will further causes increased abundance of tropical insect species ta higher altitude. An example of range expansion: Litchi plants with severe erinose symptoms in young and developing leaves were detected in Jan 2008 in an orchard of 3,000 thirteen year old litchi plants of cultivar 'Bengal' in Limeria city, Sao Paulo State (581 m asl). This was the first report of litchi erinose mite (LEM) in South America. The detection of LEM in Espirito Santo State, Brazil (750 m asl) in Dec, 2012 represents its first range expansion in this country**.**

Potential migration of desert locusts: Under favourable conditions, desert locusts can rapidly increase in number and within a month or two, become gregarious. Unless checked, it leads to the formation of small groups or bands of wingless hoppers and small group or swarms of winged adults (outbreak). Temperature favourable for migration of swarms: 17-20 ^{0}C. Migration commences: 22-23 ^{0}C.

Diapause and winter mortality: A phase of dormancy is essential for most of the species of temperate regions to complete their life cycle and to prevent the low temperature of winter season. Increased temperature conditions may be beneficial for species with low frost resistance and those, which are actively feeding during winter. They are not beneficial for those species which donot need low temperatures to manifest diapauses or to increase the frost resistance [8]. Accelerated metabolic rates at higher temperatures shorten the duration of insect diapauses due to faster depletion of stored nutrient resources [29]. Warming in winter may cause delay in onset and early summer lead to faster termination of diapauses in insects, which can then resume their active growth and development. This implies that increase in temperature at a range of 1-5 ^{0}C would increase insect survival due to low winter mortality, increased population build up, early infestations and resultant crop damage by insect pest under global scenario [30]. Winter mortality of adults of *Nezara viridula* was examined in the late March at 16 fixed overwintering sites from 1962 to 1967 in Wakayama and suggested that every 1 ^{0}C rise in temperature decreases winter mortality by about 16.5%.

Effect of rainfall on insect pests of fruit crops

Precipitation – whether optimal, excessive, or insufficient – is a key variable affecting crop-pest interactions. Abnormally cool wet conditions can also cause severe insect infestations. Some insects are sensitive to precipitation and are killed or removed from crops by heavy rains. In some northeastern US states, this is an important consideration while choosing management options for many pests [31]. For some insects that overwinter in soil, such as the cranberry fruit worm and other cranberry insect pests, flooding the soil has been used as a control measure [32]. During 2002, there was an outbreak of two spotted spider mite, *Tetranychus utricae* Koch in Shimla, Mandi and Kullu districts of Himachal Pradesh [24]. It was observed that during 2002, when the rainfall was less i.e. 68.9-72.00 mm it resulted in profused egg laying by mite (40-50 eggs per leaf), on the other hand during 2001 as a result of heavy rainfall i.e. 200.00-241.00 mm egg laying was less. This study revealed that multiplication of *T. urticae* was more under dry spell. Some studies revealed that peak activity of woolly apple aphid was observed during autumn months in Himachal Pradesh due to the provision of favourable environmental conditions [33]. It was observed that rainfall kept a significant check on the nymphal movement of woolly apple aphid, even under favourable conditions [34]. The peak population of woolly apple aphid was observed during May-June in 1997, on the other hand in 1998 highest population was observed in July. This fluctuation in the population of woolly apple aphid was mainly due to decline in rainfall or late occurrence of a rainy season [35]. The total number of adults emerged in case of apple root borer, *Dorysthenes hugelyi* was directly influenced by the amount of rainfall during second fortnight of June to first fortnight of July [36].

Effect of elevated carbon dioxide on insect pests of fruit crops

Due to increased level of CO_2 concentration in atmosphere, the plants produce more biomass. This will further lead to high nutritional quality of leaves that provide a conducive climate for pests. Increased atmospheric carbon dioxide concentration will also cause an increase in C-based compounds which further lead to increase in C: N ratio resulting in low quality foliage with dilution of Nitrogen. Thus, it was observed that under high CO_2 conditions there will be increase in herbivory. Increased C: N ratio in plant tissue may slow down the insect development and increase the length of life stages, thus vulnerable to attack by parasitoids. [37] Guerenstein and Hildebrand (2008) using FACE (Free air concentration enrichment) technique studied the role and effects of environmental carbon dioxide on insect life.

6. Effect of climate change on the activity of insect pollinators

Global climate change will affect both the phenology of plants and the abundance of insect pollinators. Phenology is the timing of physiological stages such as growth and reproduction; accordingly, flowering phenology refers to the seasonal timing of flowering. Temperature, moisture and photoperiod are the three known factors that affect the phenology of both plants and the pollinators. Many plants have reacted to increasing temperatures by earlier flowering [38-40]. Insect pollinated plants generally react more strongly to increased warming than wind pollinated plants and species flowering early in the season appears to be more sensitive [38, 40]. The onset of flowering is correlated with mean temperature in the month of flowering or in the months prior to flowering [39, 41].

Generally, Global warming and climate change results in

- Altered phenology of plants
- Altered composition of pollinators
- Emergence of new insect pollinators
- Asynchronization between pollinator activity and plant physiology

Pest Shifts in Geographical Distributions

Due to climate change geographical distribution of pest species will also be affected, which will further affect the distribution of insect pests. Due to rise in temperature the pest species may shift to newer locations may be favourable or unfavourable for their growth and multiplication. Stephens *et al.*, 2007 studied the potential global distribution of oriental fruit fly, *Bactrocera dorsalis* using current and future climatic scenario with the help of CLIMAX model. A study of about 35 non-migratory butterflies species in Europe showed that about two-thirds have expanded their range by 120-150 miles. So, as temperature rises seasonal cues are altered and life shifts.

Effect of Climate change on Activity and Abundance of Natural enemies

Quantifying the effect of climate change on the effectiveness of natural enemies will be a major concern in future pest management programs. The higher trophic levels are more likely to be affected by climate change because they depend on the capacity of the lower trophic levels for the development and survival [42]. Changes in cropping patterns as a result of climate change will drastically affect the balance between insect-pests and natural enemies [43]. Oriental armyworm, *M. separata*, populations increase during extended periods of drought, which is detrimental to its natural enemies, followed by heavy rainfall (which is favourable to the armyworm) [44]. Increase in temperature affects the predator searching capacity, thus it affect the insect population dynamics indirectly. Shifts in climate can differentially affect the development rates of pest and predator species. In biological control system of insect pest, the temperature responses of the parasitoids determine their success in controlling pest population. The egg predator (*Cyrtorhinus lividipennis*) had increased instantaneous attack rates and decreased handling times with increasing temperatures until 32 ^{0}C. At 35 ^{0}C the attack rate and handling time decreased drastically. Therefore, the predator activity is likely to increase with increasing temperatures up to a critical temperature of about 35 ^{0}C. In addition, to affecting biological control system, climate change may cause temporal synchrony between two interacting populations. Natural selection will tend to increase synchrony between hosts and parasitoids, asynchrony may occur if host and parasitoids respond differently to changes in weather conditions [45].

The relationship between pests and predators can be profoundly affected by temperature i.e. effect of parasitoids can be encouraged or discouraged by increase in temperature. For example, below 11 ^{0}C, the pea aphid reproduction rate exceeds the rate at which lady beetle, *Coccinella septumpunctata* can consume it and above 11 ^{0}C the situation is reversed [30]. As a result of climate change the herbivores may expand their ranges i.e. they migrate in the areas where natural enemies are not present. Thus, their parasitoids may or may not follow them to their new locations. This mainly affect the monophagous parasitoids that will have difficulty in adapting new areas [46]. Natural enemies and host insect population may respond differently to changes in temperatures. It was predicted that climate change may increase vulnerability of aphids to natural enemies [25]. Parasitism could be reduced if host populations emerge and pass through vulnerable life stages before parasitoids emerge. Hosts may pass though vulnerable life stages more quickly at higher temperature, reducing the opportunity of parasitism. Rising temperatures may also have a negative effect on delicate natural enemies such as Hymenopteran parasitoids and small predators. Temperature not only affect the rate of insect development but also has a profound effect on fecundity and sex ratio of the parasitoids [47, 48]. It also decreases longevity, mobility, ability to orient towards odors, and learning capacities. The endosymbiont bacteria associated with either parasitoids or their insect hosts are also suppressed by short exposure to high temperatures. Because climate change affects the insect hosts and their parasitoids differently, it may lead to a change in the distribution range of different species, resulting in rearrangements of insect communities, including the parasitoids [46]. Climate change will also disturb the predator-prey and parasitoid-host interactions and even alter the balance between insect pests, natural enemies and host plants because of alteration in their synchrony [49].

Some studies also suggest that higher temperature increase the probability that a host will kill its parasitoids. For instance, parasitism of caterpillar *Spodoptera littoralis* by the parasitoid *Microplitis rufiventris* is less efficient at 27 ^{0}C than at 20 ^{0}C [50]. Parasitoid populations may also be disrupted by extreme events and variable climate. A large worldwide study of field collected caterpillars have shown that increased variability in climate leads to reduced parasitism rates. Reduced parasitism rates are likely due to increased lags and disconnections rates between herbivores and their carnivores that occurs as climate variability increases [51]. Therefore, the interactions between insect pests and their natural enemies need to be studied carefully to devise appropriate methods for using natural enemies in pest management programs in the future.

Adaptation and Mitigation strategies

Adaptation refers to an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects that moderate, harm or exploit beneficial opportunities. Climate change mitigation encompasses the actions being taken, and those that have been proposed, to limit the magnitude and/or rate of long term global warming included climate change.

- Monitoring, quarantine check and different control measures can be applied to control the spread of pests under a warming climate.
- Soil testing should be preferred before crop sowing as a healthy soil, with optimal physical, chemical and biological properties increases plant resistance to insects and diseases.
- Excess use of nitrogen should be avoided as such excess use of nitrogen make a crop more susceptible to diseases and pests.
- Follow crop rotation, green manuring, use of natural enemies for the control of insect-pests of fruit crops.
- Polyculture techniques are less susceptible to pests than monoculture.
- Rescheduling the crop sowing date in relation to the projected changes in pest incidence and extent of crop losses in view of the changing climate.
- Application of Geographic Information System (GIS)

Conclusion

Changes in climatic conditions will trigger major changes in arthropod diversity, geographical distribution of insect-pests, pest and plant interactions, activity and abundance of natural enemies, and efficacy of crop protection technologies for pest management. Pest number will continue to fluctuate from season to season depending on weather conditions. Distribution of insect-pests and their natural enemies will also be influenced by changes in cropping pattern. Global warming will also reduce the effectiveness of host plant resistance, transgenic plants, natural enemies, biopesticides and synthetic chemicals for pest management. As a result, economic relationships between costs and benefits of pest control measures are expected to change. Therefore, there is a need to generate information on the effects of climate change on insect pests in order to develop different technologies that will be more effective and economical in the future under global warming and climate change.

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