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Impact of Climate Change on Pest Biology, Behaviour and Their Distributions

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Increased temperatures, rising CO2 levels, and changing precipitation patterns are influencing agricultural production. These changes can lead to the expansion of insect pests geographic distribution, increased survival during overwintering, more generations per year, altered synchrony with plants, changed interspecific interactions, higher risk of invasion by migratory pests, increased incidence of insect-transmitted plant diseases, and reduced effectiveness of biological control. There is a serious risk of economic losses in crop production. Human food security is challenged due to potential disruptions in agricultural systems. Climate change necessitates adaptive management strategies to address evolving pest dynamics. Future research should focus on developing modified integrated pest management tactics to cope with changing pest statuses. Monitoring climate and pest populations is crucial for understanding and predicting the impact of climate change on insect pests. This review examines the climate change effect on insect pest

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biology and behavior and explores the potential use of modern pest monitoring technologies, modeling prediction tools can aid in forecasting and planning for potential pest outbreaks. Integrated pest management (IPM) approaches should be adapted to incorporate the changing dynamics influenced by climate change. This may involve a combination of chemical, biological, cultural, and mechanical control methods.

Keywords: Climate change; temperature; CO2; pest; dynamics.

1. INTRODUCTION

There is a growing concern about the global warming being caused due to excess emission of several naturally occurring gases like carbon dioxide, methane, nitrous oxide and ozone. IPCC projects that the global mean temperature may increase between 1.4 and 5.8 degrees Celsius by 2100. It is also assumed that there will be an increase of 0.1^o C in both minimum and maximum temperatures for each degree of latitude. Thus, greater warming is expected at higher latitudes than in the tropics. The geographic distribution, vigour, virulence, and agricultural impact of weeds, insects, and plant pathogens will be affected by climatic changes accompanying the global greenhouse effect. Physiological and biochemical changes induced in host crop plants by rising CO_2 may affect feeding patterns of insect pests. Compilation of climatic thresholds for phenological development of insect pests reveals the potential for shifts in pest behaviour induced by global warming and other climatic change [1]. Generation times may be reduced, enabling more rapid population increases to occur. Pole ward migration may be accelerated during the crop season. The epidemiology of plant diseases also will be altered. Prediction of disease outbreaks will be more difficult in periods of rapidly changing climate and unstable weather particularly where insects are involved in the transmission of the diseases. Environmental instability and increased incidence of extreme weather may reduce the effectiveness of pesticides on targeted pests or result in more injury to non-target organisms. Biological control may be affected either negatively or positively. Overall, the challenge to agriculture from pests probably will increase [1] various possible implications of the global warming on the pests with particular reference to insects is being reviewed in this chapter based on various works carried out world over to know the effect of climate change on the insect pests and disease vectors with particular reference to Horticulture.

2. CLIMATE CHANGE AND HORTICULTURAL CROP PESTS-INDIAN SCENARIO

As the change in temperatures, new pests (moths and butter flies) will migrate to new areas. Already introduced pests like American leaf miner, *Liriomyza* may spread to new areas northwards with the increase in temperatures. Non-indigenous pests may become established initially in protected crops, as lot of plant material is being imported for protected cultivation particulary, ornamentals. Gradually these pests with establish in field crops subsequently, as the climate changes. In India, fruit fly, *Bactrocera zonata* is generally restricted to north India. Till late 1990's this fruit fly was over wintering in north India. But during the last 3-4 years adults are being observed during winters in Uttar Pradesh most probably because of increase in soil temperatures due to climate changes. Among vegetables, sucking pests are likely to increase such as thrips, mites, and leafhoppers with the increasing temperatures with climate change. In okra, leafhoppers will increase. Diamond back both may increase up to 28-35 ^{O}C range and thereafter in areas where temperature increases, the incidence decreases. Similarly leaf miner, *Liriomyza* incidence will increases up to 30-35 ^{o}C. Obviously, there is considerable uncertainty attached to climate change predictions and this is true also of likely changes in pest pressure in the future. Some pests will inevitably become a more serious problem, whilst others may decline. Whatever the long-term consequences of climate change, pest numbers will undoubtedly continue to fluctuate from season-to-season, depending on the particular combination of weather conditions that occurs each year.

2.1 Some Expected Trends

Helicoverpa armigera is appearing in severe proportions once in 5-6 years may be due to change in the migration behaviour and shift in the host plants as influenced by climate change.

Whitefly, *Bemisia tabaci* menace has been increasing in the last two decades because of climate change coupled with change in the crop varieties and new agronomic practices. Development of temperature tolerant 'B' biotype is recorded in tomato from Kolar region of Karnataka. The B biotype was first recorded in Kolar district of Karnataka during summer season in the year 1999 and from since then the biotype was spread to various parts of Karnataka and Andhra Pradesh. Because of change in temperature regimes, crops and pests may spread into newer areas, where hitherto are not suitable for their development and multiplication [2]. Eg. Fruit fly, *Bactrocera* sp. Introduced pests like American serpentine leaf miner, *Liriomyza* may spread to new areas northwards with the increase in temperatures particularly, warmer winters. Non-indigenous pests may become established initially in protected crops, as lot of plant material is being imported for protected cultivation, particularly ornamentals. Gradually these pests will establish in field crops subsequently, as the climate changes. Incidence of thrips has been increasing on onion, rose, grapes and mealy bug on grapes in the recent past. Red spider mite, *Tetranychus urticae*, which was considered as minor pest two decades back, has been regularly appearing on crops like tomato, grape and other ornamental crops. This is the pest which likes higher temperatures for its multiplication and will get much benefit with the raising temperatures for faster development resulting in a greater number of generations. On mango, extensive rains trigger vegetative shoots and also the incidence of leaf miner, *Rhynchaenus mangiferae* and shoot borer, *Chlumetia transversalis*. Temperature, especially the minimum (night) temperatures positively favour the incidence of fruit fly, *Bactrocera* spp. on mango. When flooding takes place in relatively larger area in mango belts, may result in the killing of the resting stages of pests (pupae) like fruit fly and may lower the incidence of these pests in the coming season. In India, fruit fly, *Bactrocera zonata* which was generally confined to north Indian conditions, of late is also observed in south India. Till late 1990's this fruit fly was over wintering in north India. But during the last 4-5 years, adults are being observed during winters in Uttar Pradesh most probably because of increase in soil temperatures due to climate change. Higher temperatures (more than 40^{o}C coupled with lower humidity prevents establishment of stone weevil, *Sternochetus mangiferae* on *Rhipiphorothrips* sp. was the major thrips species on horticultural crops like grapes and rose till late 1980's. From 1990's onwards, this pest was replaced by *Scirtothrips dorsalis*, both on these crops. Probably the changing temperature conditions are more congenial to *S. dorsalis* more than *R. cruentatus* which needs some studies, for establishing the reasons. In India, there may be a change in natural distribution range shifts of pests like fruit flies, *Bactocera* sp., green stink bug, *Nezara viridula*, sweet potato weevil, *Cylas formicarious* which are presently in tropical and subtropical climates and may shift to temperate zone. Some of the pests like blossom midge, *Contarinia maculipennis* (Diptera: Cecidomyiidae)

2.2 Anticipated Pest Problems Due to Drought

Drought may enhance the incidence of pests like termites, mites *etc.* Affects the diapause of insect stages and resulting in abnormal build-up of the pest in the next year. Drought stress may result in higher damage to plants due to insects eg. Leaf miners and thrips. May affect the tritrophic interactions. May affects the efficacy of biocontrol agents.

2.3 Effect of Climate Change on Pests

The Overall Effect Of Global Climate Change On Pests Can Be Categories Into

I. Direct Effect of climate Change on Pests

i) Expansion of Habitat Range of Pests
ii) Change in Migrating Behavior
iii) Changes in Over Wintering Success
iv) Changes in Interaction between Species
v) Effect of Pest-Natural Enemy Interactions

II. Indirect Effect Through Host Plants

i) Effect of Increased Temperature
ii) Effect of Increased CO_2
iii) Effect of Increased Pollutants (Ozone and Nitrous Oxide)
iv) Effect of Changes in Host Plant Distribution

Various Climate change factors can affect the pests either positively or negatively. Various implications of the climate change on pests are discussed under different heads.

3. EFFECT OF INCREASED TEMPERATURE

Increased temperatures may alter host physiology and resistance. Elevated temperatures may cause breakdown in temperature sensitive resistance. Increase in food quality due to increase in nitrogen content in plants under stress conditions caused by high temperature can result in sudden resurgence of insect pests' population [3]. Moreover, defensive system of plants is lowered under stress conditions, and they become more susceptible to pest attacks. Conversely, in some forage species, there is increased lignification at higher temperatures, which can enhance the level of host resistance to pathogens. Insects are poikilothermic in nature *i.e.,* their surrounding temperatures determine their development. The effect of temperature on insects which limit their range, over wintering, populations growth rate, number of generations per annum, length of growing season, crop-pest synchronization, intraspecific interaction, dispersal, migration and availability of host plants and refugia. Insects may gain or lose based on the prevailing temperatures in which they are living.

Some of the insects in the tropics are already living at the limit of their temperature range and any further increases could quickly kill them off with huge repercussions for tropical habitats, which rely on insects for everything from pollination to waste disposal. It was found that a rise in average temperatures in the tropics of just 1^0C or 2^0C could be enough to exert a significant and harmful effect on the survival of a wide variety of important insects. Insects are critical to the health of tropical habitats because they perform vital services such as breaking down organic matter, pollinating flowers to produce fruits and nuts and providing sustenance for creatures higher up the food chain. Insects in colder regions may survive and proliferate because they are still at the lower end of the temperature. For example, pea aphid sampled at 52°N, has a critical thermal limit of -10°C to 35°C. But the maximum temperature it has lived in has been 20°C. But in case of a pod-sucking bug, a tropical insect sampled at 6°N, the limit is 15-32°C and the maximum temperature has already gone up to 32°C. "In the tropics, many species live at or near thermal optimum, a temperature that lets them thrive. Once temperature gets above the optimum, fitness levels will decline quickly,".

With the climate change, under tropical conditions the winter duration will be reduced there by affecting the hibernation of the insects resulting in the more multiplication of the pests with a greater number of generations. When the temperatures are above 35 ^{o}C lepidopterous pests may be reduced and smaller pests like leaf miner, thrips, mites and whiteflies may increase in numbers. However, under temperate conditions, caterpillar pests may increase with the change in the climate. Peurbanisation is the order of the day. Enhanced CO_2 emission along with other pollutants coupled with high temperature will result in the complex changes in the pest systems particularly under horticultural ecosystems.

3.1 Temperate Regions

The increasing temperature in the temperate latitudes will result in less cold stress from low minimum temperatures, longer growth seasons with more degree-days for development and more heat stress of temperate species from higher maximum temperatures. As these changes take place, day lengths remain unchanged so species with close linkages to day lengths will have their dormancy, diapause, migration or reproductive processes disrupted. In addition, they will be at risk of a loss of synchrony with other species of plants and animals with which they interact but which respond differently to temperature changes. All of these changes will contribute to shifts in the geographical distributions of pests. Temperate species will push further towards the Polar Regions while tropical and sub-tropical species will encroach on the temperate regions.

3.2 Tropics

In the tropics the most likely changes of biological significance will be related to changes in available moisture. With lower average rainfall scenarios, and more intense rainfall evens dispersed between longer dry periods, the seasonal growth of many pests and their associated biota are likely to alter. More prolonged and intensive droughts are expected. Crop pests and pathogens may be affected by changes in the crop canopies as enhanced concentration of CO_2 stimulate growth of foliage in situations where other nutrients are not limiting. There is clear evidence that climate change is altering the distribution, incidence and intensity of animal and plant pests and diseases. In India, there will be a change in natural distribution range shift of pests like fruit flies, *Bactrocera* sp., green stink bug, *Nezara viridula*, sweet potato weevil, *Cylas formicarius* which are presently in tropical and subtropical climates and may shift to temperature zone. Some of the pests like blossom midge, *Contarinia maculipennis* (Diptera: Cecidomyiidae) may result in expansion of host range from orchids to various sorts of crops [4].

Migrant moths of the Old World bollworm, *Helicoverpa armigera* had a phenomenal increase in the United Kingdom from 1969-2004 and there have been outbreaks at the northern edge of its range in Europe; cottony cushion scale, *Icerya purchasi* populations appear to be spreading northwards perhaps as a consequence of global warming; and cottony camellia scale, *Pulvinaria-Chloropulvinaria-floccifera* has become much more common in the United Kingdom, extending its range northwards in England and increasing its host range in the last decade or so, which is almost certainly in response to climate change. In Sweden this species was previously only known as a greenhouse species, but is now established as an outdoor species. A particular case study reported by Yukawa showed that *Nezara viridula*, a tropical and subtropical crop pest, is gradually moving northward in southwestern Japan, possibly due to global warming, replacing the more temperate species *Nezara antennata*. The main drivers of plant pest change include increases in temperature, variability in rainfall intensity and distribution, change in seasonality, drought, CO_2 concentration in the atmosphere and extreme events (eg. Hurricanes, storms), intrinsic pest characteristics (eg. Diapause, number of generations, minimum, maximum and optimum growth temperature of fungi, interaction with the host) and intrinsic ecosystem characteristics (eg. Monoculture, biodiversity) also affect change. Emerging pests are often plant pests of related species known as new encounter pests, which come into contact with new hosts that do not necessarily have an appropriate level of resistance, or are plant pests introduced with out their biological control

It is predicted that in the absence of confounding factors, such as interactions with other organisms and land use change, climate warming of the order of 1°C could advance first and peak appearance of most butterflies by 2-10 days [5].

4. EFFECT ON CLIMATE CHANGE ON PESTS

4.1 Climate Change and Nematodes

There is a close correlation between soil temperatures and the distributions of some plant-parasitic species, such as *Longidorus caespiticola* [6]. A 1^0 C rise in temperature would allow this species to become established further north in Great Britain. Root knot nematode, (*Meloidogyne incognita*) was recently found in the Netherlands, a species that previously was considered restricted to the Mediterranean area.

The development of temperate nematode pests such as potato cyst nematode (*Globodera pallida*) and root knot nematode (*M. hapla*) has been observed on Potato roots from localities where these nematodes were absent earlier. An increase of 2-3 ^{0}C higher soil temperatures in the traditional mild climate areas was observed during the past 20 years, which might have acclimatized the pest to develop under warmer climate [7]. Thus, increase in soil temperatures at traditional localities may encourage the nematode spread in the newer areas.

4.2 Homoptera and Climate Change

Aphid biology is influenced by temperature, which initiates development, fecundity, movement and morphological determination. In *Myzus persicae* increase of mean temperature by 1ºC advances the time of progeny migration by two weeks, also well evident in *Acyrthosiphon*, *Rhopalosiphum*, *Sitobion*. The impact of temperature on aphid damage and ability of many species to act as vectors are well known. Temperature also contributes to morph determination besides differences in responses between species, between clones within species and within morphs within a clone. Aphids are very sensitive to warmer conditions with a reduced tendency for alate production, lower migratory potential and delay in sexual morph production. So, the direct effect of warming on aphids is likely to beneficial in relation to individual performance, with important consequences on population dynamics and their pest status. Various aphid species like *Aphis gossypii*, *Myzus persicae etc*. which are worldwide in distribution, may increase by a greater number of generations a year due to lower developmental zero point and low thermal totals required for one generation, resulting in more infestation.

4.3 Climate Change and Disease Vectors

Many of the diseases in horticultural crops are transmitted by insect vectors. Existing studies of climate change on organisms suggest that direct effects of temperature are likely to be larger and more important than any other factor. The main effect of temperature in temperate regions is to influence winter survival of vectors. Natural spread of vectors, pests and diseases is accelerated towards the North, as former climate barriers are no long effective. This results in more severe outbreaks of plant-disease vectors like aphids, whiteflies, thrips *etc*., an extension of the period of disease infection further into the growing season and also introduction and establishment of new vector species. More vectors survive from one vegetation period to the next leading to earlier and faster development of the transmitted diseases. Citrus greening disease is transmitted by psyllid, *Diaphorina citri*. Presently the disease is more prevalent in tropical and subtropical countries in the world. Climate change may push the disease in temperate zones.

5. EFFECT OF ENHANCED CO_2 LEVELS ON INSECT PESTS

Increase in C:N ratio tends to have a detrimental effect on polyphagous insects leading to increase in carbon based allelochemicals. Further, the negative response of insects to elevated CO_2 is that they accumulate more carbon, with an increase of C:N ratio, so that insects are faced with nutritionally deficient host plants resulting in a N-dilution effect [8]. Thus, under higher CO_2 conditions feeding by herbivores will be high to derive more amino acids. Moreover, at elevated CO_2 there is greater partitioning of assimilation of roots in crops such as carrot, radish and sugar beet. Due to increased carbon storage in roots, losses from soil borne pests may diminish under climate change [9]

The principal effect on herbivores of increasing the carbon supply of leaves is due to reduction of leaf nutrient concentration. For example, *Pseudoplusia includens* feeding was 30% greater on leaves from the 650-µl/litre treatments than on leaves from the 350 ul/litre treatment. This study suggests that feeding by herbivores on the leaves of C_3 plants may increase as the level of atmospheric carbon dioxide rises [10]. Similarly in case of *Trichoplusia ni* elevated atmospheric carbon dioxide levels of 1000 p.p.m. significantly increased consumption of foliage when compared with ambient levels of 340 p.p.m. The percentage leaf area of plants consumed by *T. ni* larvae was not affected by carbon dioxide concentration, suggesting that increased plant growth resulting from raised atmospheric carbon dioxide may benefit the plant proportionately more than the insect [11].

Brevicoryne brassicae reared on *Brassica oleracea* produced significantly less offspring at elevated CO_2, whereas the opposite was found for *M. persicae* on the same host. No response was found for *M. persicae* on *Senecio vulgaris*. When populations of *B. brassicae* and *M. persicae* were followed for a longer period, no differences were observed in population sizes. Comparisons between different experimental systems showed that long-term population responses to elevated CO_2 cannot be reliably predicted from detailed measurements on individual aphids [12].

Fajar *et al.,* (1989) studied the effects of enriched CO_2 atmospheres, on natural plant-insect herbivore interactions [13]. Larvae of a specialist insect herbivore, *Junonia coenia* (Lepidoptera: Nymphalidae), were reared on, *Plantago lanceolata* (Plantaginaceae). Those larvae raised on high-CO_2 foliage grew more slowly and experienced greater mortality, especially in early instars, than those raised on low CO_2 foliage. Poor larval performance on high-CO_2 foliage was probably due to the reduced foliar water and nitrogen concentrations of those plants and not to changes in the concentration of the defensive compounds, iridoid glycosides.

6. ELEVATED TEMPERATURE AND CARBON DIOXIDE INTERACTIVE EFFECTS

Doubling of the current atmospheric CO_2 concentration, and an increase in global mean annual temperatures of 1.5-6°C, have been predicted to occur by the end of this century. Whilst the separate effects of CO_2 and temperature on plant-insect interactions have been examined in a number of studies, few have investigated their combined impact. Johns and Hughes, [14] have conducted a factorial experiment to explore the effect of a doubling of CO_2 concentration and a 3°C temperature increase on the development of a complete generation of the leaf-miner, *Dialectica scalariella*, in the host plant Paterson's Curse, *Echium plantagineum*. Elevated CO_2 increased biomass, reduced leaf N and increased C: N ratios in the host plants. Leaf thickness also increased under elevated CO_2, but only in the high-temperature treatment. Female *D. scalariella* did not discriminate between plants grown at the different CO_2 levels when ovipositing, despite the reduction in foliage quality under elevated CO_2. Overall, the negative response of *D. scalariella* to elevated CO_2 was greater than for many species of free-living insects, presumably because of the limited mobility imposed by the leaf-mining habit. Development was accelerated at the high temperature and slowed under elevated CO_2. The net result was a reduction in development time of 14 days in the elevated CO_2/high temperature treatment, compared to the ambient CO_2/low temperature treatment. Larval survivorship and adult moth weight were both affected by a significant interaction between CO_2 and temperature. At the low temperature, CO_2 had little effect on survivorship, but at the high temperature, survivorship was significantly reduced under elevated CO_2. Similarly, elevated CO_2 had a stronger negative effect on adult moth weight when combined with the high-temperature treatment. Thus, high temperature accelerated insect development to such an extent that the larvae did not have sufficient feeding time to compensate for the poorer quality of the foliage. The frequency with which interactions between CO_2 and temperature affected both plant and insect performance in this study highlights the need for caution when predicting the effects of future climate change on plant-insect interactions from single-factor experiments.

7. EFFECT OF INCREASED POLLUTANTS (OZONE AND NITROUS OXIDE)

Ozone is likely to have an adverse effect on plant growth. It appears plants are less sensitive to nitrous oxide. Atmospheric pollutants directly or indirectly affect the process of water and nutrient uptake from soil and making the plant weak thereby affecting the insects.

8. EFFECT OF CHANGES IN HOST PLANT DISTRIBUTION

Climate change will affect the geographical distribution of plant species and their growth patterns. Spatial changes of crops and cropping systems for sustained productivity an imminent under climate change scenario (Carter *et al*., 1991), affecting the distribution of insect pests [15].

9. PEST SHIFTS IN GEOGRAPHICAL DISTRIBUTIONS

Climate change will affect the geographical distribution of plant species, their growth patterns thus affecting the distribution of insect pests. Because of change in the temperature regimes pests may spread into newer areas where hitherto are not suitable for insect development and multiplication. This situation can be explained with the help of oriental fruit fly, *Bactorcera dorsalis*, a major pest throughout South East Asia and in a number of pacific Islands. Stephens *et al.,* (2007) studied with the help of CLIMEX model the potential global distribution of *B. dorsalis* under current and future climate scenarios [16]. Under the current climatic conditions, its projected potential distribution includes much of the tropics and subtropics and extends into warm temperate areas such as southern Mediterranean Europe. The model projects optimal climatic conditions for *B. dorsalis* in the southeastern USA, where the principal range-liming factor is likely to be cold stress. As a result of climate change, the potential global range for *B. dorsalis* is projected to extend further pole wards as cold stress boundaries recede. However, the potential range contracts in areas where precipitation is projected to decrease substantially. Similarly, the pest has been free in many areas in India. With the changing climate scenarios this pest may spread to newer areas on Horticultural crops. The significant increases in the potential distribution of *B. dorsalis* projected under the climate change scenarios suggest that the World Trade Organization should allow biosecurity authorities to consider the effects of climate change when undertaking pest risk assessments. Climatic warming will allow the majority of temperate insect species to extend their ranges to higher latitudes and altitudes. Minimum rather than maximum temperature is important in determining global distribution of insect species.

A study of 35 non-migratory butterflies' species in Europe found in recent decades, that about two-thirds have expanded their range by 20-150 miles and many plants flower a week earlier than they did 50 years ago. So as temperatures rise, seasonal cues are altered and life shifts in space and time.

Warmer winter temperatures are likely to increase the probability of the spread of the American leaf miner, *Liriomyza* that has been introduced into our county some time back and more prevalent in southern states than northern states.

10. EFFECT OF CLIMATE CHANGE ON MIGRATION AND OVER WINTERING OF PESTS

Migration in insects occurs for escaping adverse conditions. However, with the increase in temperature with climate change, the unfavorable areas may become suitable thereby eliminating the need for migration. Any increase in temperature will result in greater ability to over winter at higher latitudes, ultimately causing poleward extension of insect distribution. For example, cabbage butterfly migrates from hills to plains in winter and back to hills in summer. Global warming may affect this migration and extend distribution of the pest further north. However, the activity of this pest may decline in the plains [17]. Aphids are major pests on many horticultural crops and are most likely affected by temperature change as a result of their low developmental threshold, low thermal constant and multi voltinism [18].

With the rise in temperature, onset of hibernation may be delayed while it may be suspended earlier than usual in spring, thereby increasing the active period of pests, which would result in greater damage [19]. Where an insect chooses to over winter may affect its survival. For example, some insects over winter near the soil surface. In this case, snow cover can provide an excellent insulation, and if this is reduced, these insects might not survive a very cold winter. On the other hand, an increase in temperature and a longer growing season could result in an extension of ranges of plants and animals, with new insects being able to establish themselves in a region where they were previously unable to survive.

Migratory pests, in particular locusts, are totally dependent on rain, temperature and vegetation and their habitats change rapidly. The desert locust (*Schistocerca gregaria*), like other locusts, can change its behavior and physiology from solitary grasshoppers to gregarious stages that from swarm. Solitary desert locusts occur at low density in the recession area, which covers North Africa, the Sahel, the Red Sea countries and parts of India, Pakistan, Iran and Afghanistan [20]. The outbreak area reaches from Mauritania to India and from southern Europe to Cameroon and Tanzania. Outbreaks and plagues originate in the recession areas when there are several cycles of good breeding conditions. Although the effects of climate change on this system are difficult to judge, climate scenarios with more winter rain in the Sahel may provide better breeding conditions.

11. CHANGES IN INTERACTION BETWEEN SPECIES

Rapeseed-mustard is infested by two aphid species, *Liphaphis eysimi* and *Myzus persicae*, the former being dominant during severe winters and the latter during mild winters [15]. With rise in temperature, higher incidence of *Myzus persicae* may be witnessed. Such faunal shifts may also take place in other crops [21]

12. CLIMATE CHANGE: PEST-NATURAL ENEMY INTERACTIONS (INCLUDING TRITROPHIC INTERACTIONS)

Temperature and rainfall can influence the efficacy and performance of bioconrol agents like parasites, predators and microbials. With the increase in temperature, predators of aphids on *rabi* crops may become more active than at present. Besides, many parasitoids may lose the “tracking” ability for the host caterpillars to deposit the eggs due o unsolicited appearance of heavy rains. Wasps for instance, may lose the critical “window period” or hatching out of cocoons due to late onset of rains. On the contrary, some species of pests like aphids are adversely affected due to fungal outbreaks during the rains. The consequence on the population dynamics may lead to substantial increase in the use of agrochemicals and related load on the environment.

13. EFFECT OF DROUGHT ON INSECT INCIDENCE

Under the changing climatic conditions drought will have the following effects on the pest status. I) Drought may enhance the incidence of some pests Eg. Termites; ii) affect the diapause of insect stages. Under drought conditions eggs of grasshoppers may undergo diapause and results in abnormal build up of the pest populations in the next year iii) Drought stress may result in higher damage to plants due to insects Eg. Leaf miners. iv) Drought and host plant vs insect’s species: Frequent droughts may lead to complex rapid (increase and decrease in numbers) in ecosystems where different species (butterflies, moths, carabid beetles) of insects are involved and needs to be considered in planning conservation strategies v) Drought - natural enemies of the pests**:** drought affects the efficacy of biocontrol agents [22].

14. CLIMATE CHANGE AND PESTICIDES

The consequence on the population's dynamic may lead to substantial increase in the use of agrochemicals and related load on the environment. Higher temperature leads to faster completion of generation cycle of the pest which indirectly provokes the indiscriminate use of pesticide and hence pesticide resistance. Thus, climate change could affect efficacy of crop protection chemicals through i) changes in temperature and rainfall ii) morphological and physiological changes in crop plants. Globally, climate change models predict an increase in probability of intense rainfall, which could result in increased pesticide wash off and reduced pest control. In contract, increased metabolic rate at higher temperature could result in faster uptake by plants and higher toxicity to pests. The rates of pesticide application thus have to be modified carefully according to new situations as they arise.

Climate change may also affect ability to control pests. For example, high temperature is reported to reduce the effectiveness of some pesticides. Humidity levels can also modify their efficacy, as can the timing and amount of rain following their application. On a simpler level, rain can affect growers' ability to apply the pesticide at the time of most need, possibly an increasingly likely scenario. If pests are able to complete more generations in a season, then this may lead to greater pesticide use, which in turn may lead to the more rapid development of pesticide resistance. Strategies to avoid the development of resistance need to be planned in advance and rely on the availability of a range of pesticides and/or alternative control methods. This scenario is mot likely for some the horticultural crop pests like mites, leaf miners, thirps *etc*.

Mealy bugs are emerging as a major problem in many of the Horticultural crops. Fish oil rosin soap (FORS) is highly effective against mealy bugs but is found to be phytotoxic on some plants. So, with climate change, there is a high risk of FORS phytotoxicity with increasing temperature. The vulnerability of horticultural industries in Australia to the Queensland fruit fly *Bactrocera tryoni* under climate change was studied. Climatic warming threatens the sustainability of area freedom in the Fruit Fly Exclusion Zone (FFEZ) and is likely to increase damage and control costs to commercial growers in endemic areas, except in northern Australia. Costs to mainland apple, orange, and pear growers are estimated to increase by $3.1, $4.7, and $12.0 million with increases of 0.5°C, 1.0°C, and 2°C, respectively. Thus, the fly poses a real threat to southern States under modest projected increases in temperatures. The extent of the likely cost increases raises questions about the industries' ability to pay and remain competitive [23].

15. ADAPTATION TO CLIMATE CHANGE

Global climate change would cause alterations in sowing dates of crops like vegetables, annual ornamental crops among various horticultural crops, which may alter host pest synchrony. There is need to explore changes in host-pest interaction under early, normal and late sown conditions in order to recommend optimum sowing dates for reduced pest pressure and increased yield of vegetable crops. Elevated temperatures may lead to beak down of temperature sensitive resistance and durability of resistance may be threatened due to increase in number of pest generation. This may lead to more rapid evolution of pest biotypes. This way many resistant cultivars may be lost. Breeding of cultivars for both pest and drought resistance will be a more viable option. Evolve strains of natural enemies for higher temperature tolerance.

16. CONCLUSIONS

Based on the above discussion the main conclusion drawn on the impact of climate change on pest damage are as follows: The reproductive ability of insect pests is likely to be affected by any change in the nutritional value of food plants due to climate change. Thus, for example, if carbon dioxide in the atmosphere keeps increasing, it is likely to affect nutrient balance in plants and could render them more or less susceptible to insect attack. As the climate gradually warms, it will lead to change in the composition of pest fauna in different areas. The great mobility and high population growth rate of many pest species will ensure change in the distribution of pests. The length of growing season for tropical and subtropical pests will increase, resulting in more generations and hence greater pest impact. Over wintering of pests will increase producing large populations as a base for build up in number in the following season. In some cases, hibernation may not be required by pests thereby more generations may be produced resulting in more crop damage. Many pest species may have their diapauses strategies disrupted as the linkages between temperature and moisture regimens and day lengths are alerted. There will be increased variability in pest impact caused by greater variability in climate. Pest-plant interactions will change and may cause increased damage. Relationship between pest and natural enemies will change affecting the status of pest species. Economic relationship between the cost and benefit of pest control measures will change as a result of changes in the supply of plant and animal products. Climate change is likely to alter the balance between insect pests, their natural enemies and their hosts. There is a need for the study of combined effects of several factors (Temperature, CO_2 and rainfall) on pests as well as on the performance of biocontrol agents like parasites, predators and microbials. Studies related to CO_2, temperature, pollutants such as ozone and their influence on insects needs to be studied. These studies need to have priority if we are to establish how different forms of plant feeding insects respond to such changes, notably the impact of global temperature rise in relation to abundance and distribution of plant feeding insects.

AVAILABILITY OF DATA AND MATERIALS

The authors confirm that the data supporting the findings of this study are available within the article.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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