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Impact of climate changes on insect pest and integrated pest management: A review

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Abstract
Global climate change caused by increased giving out of greenhouse gases affect the agro-ecosystems in many ways, outcome of which depend on the combined effects of environmental temperature, precipitation and other global changing factors. Insects respond to climate change by different ways *i.e.*, changes in an insect population's physiology, biochemistry, biogeography and population dynamics. An insect population's response to a rapidly changing climate may also be erratic when insects interact with different competitors, predators and parasitoids. Due to the climate change, there is a raise in the number of insect pest population, out breaks of insect, increased number of generations and development of resistant biotypes. Climate changes cause negative impact on the natural enemies' population. This also can manipulate the overall food production system that can be at critical risk from the impacts of climate change.

Keywords: Climate changes, temperature, CO_2, precipitation, natural enemies

1. Introduction

Climate change is the term used to describe a gradual increase in the average temperature of the earth atmosphere and its oceans, a change that is said to be changing the earth's climate forever. Climate change has become a household topic of discussion with more scientists getting involved in scientific research on the aspect while politicians trying to derive mileage from the paradigm. Global temperature has been steadily rising since 1900 with an increase of about 1 °C since then. The greatest increase has been in northwestern North America, but India's temperature has increased between 0.2 °C and 1 °C. The majority of the warming was observed over the last 50 years is attributable to human activities. The global mean surface temperature is predicted to increase by 1.4 to 5.8 °C from 1990 to 2100. If temperatures rise by about 2 °C over the next 100 years, negative effects of global warming would begin to increase to most regions of the world [1]. Climate change in the usage of the Intergovernmental Panel on Climate Change (IPCC) referred to 'a change in the state of the climate that can be recognized (*e.g.* using statistical tests) by changes in the mean and/or the changeability of its properties that persist for an extensive period, typically for decades or longer. It refers to any change in climate after a while, whether due to natural changeability or as the outcome of human activity [2].

This change is recognized mainly to the overexploitation and misuse of natural resources for various anthropogenic developmental activities such as increased urbanization, deforestation and industrialization resulting in aberrant weather events like changes in rainfall patterns, frequent droughts and floods, increased intensity and incidence of heat and cold effect, outbreaks of insect-pest and diseases etc. affecting very much, many biological systems and ultimately the human being.

2. Climate change and pest status

Agro-ecosystem environment is largely governed by communication between abiotic (temperature, humidity, rainfall, soil factors, pollutants etc.) and biotic (crop- plants, weeds, insect-pests, pathogens and nematodes etc.) factors. The abiotic stress factors modulate the effects of biotic stresses and are most harmful when arise in combination [3] greatly influence crop growth and productivity to the extent of 80% [4]. Climate change resultant abiotic environment especially changes in hydrological cycles [5] and temperature regime may vary the composition of agro-ecosystems resulting in height wise change in distribution and range of

Animals and plant species [6, 7]. Hence, in the context of global climate change, it is an extreme need of hour to address multiple stress intimidating sustainability of agricultural production system.

Insects contain the largest group of animal kingdom and play vital role in providing various ecosystem services [8]. Insects are good indicators of current human drive climate change. They have responded to warming in all predicted ways from changes in phenology and distribution to undergoing evolutionary changes. Insect are amid the groups of organism most likely to be affected by climate change because climate has a tough direct influence on their development, reproduction and survival [9]. Moreover, insects have short generation's times and high reproductive rates, so they can more like to respond quicker to climate change than long-lived organisms, such as plants and vertebrates [10]. World over research on effect of climate change on pests and diseases of crops is insufficient [11].

In India, there is limited attempt in this area for any insect-pest or disease of any crop [12]. At the population level, the adaptive probable of plant and pathogen populations may prove to be one of the most important predictors of magnitude of effects of climate change. Ecologists are now addressing the role of plant disease in ecosystem process and the challenge of scaling-up from individual infection probability to epidemics and broader impacts [13]. Climate exerts powerful effects on the supply and abundance of the earth's insect species and we should expect climate warming to create changes for many insect populations and the ecosystems they live in. Swaminathan [14] showed that the number of diseases on the same crops were much higher in tropics than under temperate conditions to show how increasing temperatures could impact incidence of plant diseases on agricultural crops. Warmer temperature generally lead to more fast development and survival in insects in mid to high latitudes, which can account for visible and definite shifts in a range of insect species more than the half century. Increased heat also advances the start of insect life cycles for the many species that use thermal cues to match the timing of life history actions with the changing seasons. Presently, most of the work associated to climate change vis-à-vis plant diseases is going on in rice (blast, bacterial leaf blight), wheat (*Puccinia, Septoria*) and horticultural (*Meloidogyne*) crops.

3. Climate changes and insect diversity

According to Chahal, *et al*., [15] climate change lead changes in insect-pest status and will extremely affect agricultural production and the livelihood of farmers in the country where larger portion of work force is directly dependent on climate responsive sectors such as agriculture. This envy an urgent need to modify crop protection measures with changed climate in order to achieve the goal of food security of the nation.

The insect diversity in a habitat show the health status of an ecosystem as they are very good indicator of environmental change [16], play an important role in food chains, are excellent pollinators for many of the economically important crops [17, 18] and contribute directly to the human economy through valuable products like silk, lac, honey and wax [19, 20, 21]. The climate change may influence the relative abundance of different insect species and the species unable to adapt the changes may be lost in the due course of time [22]. According to Anand, and Pereira [23] the Western Ghats in India is the only habitat to many unusual, endemic and exotic species of colorful butterflies in the world. In the present day circumstances, many butterfly species are under a real threat due to reduction of the natural vegetation for various anthropogenic developmental actions [24, 25].

The negative effects of climate change are accelerating the rate of biodiversity loss, worldwide. According to the Millennium Ecosystem Assessment [26] more than one-third of species in the world are at the risk of disappear and an predictable 60% of the Earth's ecosystems have been degraded in the last 50 years, with negative significance for the ecosystem flow. Nearly 99.9% of all species that ever existed have become destroyed. Up to 50% of the Asia's total biodiversity is at danger due to climate change. Many other species could also be removed as a result of the climate change and habitat destruction [27]. According to the estimation of IUCN [28] around 22 species of invertebrates (insects, earthworms, nematodes, crustaceans, spiders, etc.) are at the risk of destruction. This species extinction is largely determined by human action [29].

Global climate modify impact on plant and pest population depends on the combined effect of climate (temp., precipitation, humidity) and other element like soil moisture, atmospheric CO_2 and troposphere ozone (O_3).

3.1. Effects of increased temperature on insect pests

Insects are cold-blooded organisms (poiklothermic), the temperature of their body is around the same as that of the environment. As a result, temperature is may be the single most important environmental cause influence insect behavior, distribution development, survival and reproduction. Many of the effects of increased temperature on insect act have to do with the direct effects of temperature on insects, because insects are exothermic, they likely to be more active under warmer conditions.

A typical effect of elevated temperature is therefore to increase consumption rate and therefore decrease the time to pupation, making them less evident to natural enemies and in some cases increasing the potential number of generations per season. Yamamura and Kiritani [30] observed with a 2^{o}C temperature increase insects capacity experience one to five additional life cycles per season. If the mortality per generation does not change, the insect population will become potentially superior under global warming [31]. This detail could play a vital role in the case of multivoltine species, most of them are expected to wider their occurrence to higher latitudes and altitudes as was recorded e.g. in many cases of butterflies [32].

Bug and termites is major contributor of global warming. Among every degree the global temperature rise, the life cycle of every bug will be shorter. The quicker the life cycle, the higher will be the population of pests [33]. High temperature increase gypsy moth performance, both decreasing its development time and increase its survival time [34]. Temperature may change sexual category ratio of some pest species such as thrips [35] probable affecting reproduction rate. Insects that expend important parts of their life histories in the soil may be more progressively affected by temperature change than those that are above ground simply because soil supplies an insulating medium that will be likely to buffer temperature changes over the air [36]. Increase in temperature in winter may help to maintain the lifecycle of some pests. Lesser winter mortality of insects due to warmer winter temperature can be important in increases the insect population [37].

The association between temperature tolerance and phenology of insects was examine by Klok and Chown [38]. They defined how the current climate changes like raise temperature and decreased rainfall effect on physiological regulation and susceptibility. Coops,and Waring [39] have presented a spatial modelling practice to conclude how a sustained change in climate might change the geographic distribution of the species.

3.2 Effects of increased CO_2 on pests

CO_2 is about twice more important for temperature increase than other long-lived greenhouse gases combined. Although increased CO_2 should not directly deleteriously influence insects, the temperature increases determined by the increase in anthropogenic CO_2 already affect insects in deep ways including their distribution, nutrition, phenology and function as disease vector. Increased CO_2 levels can force both the host and the pathogen in multiple ways. Some of the observed CO_2 effects on disease may neutralize others. Researchers have shown that high growth rates of leaves and stems observed or plants grown under high CO_2 concentrations may result in intense canopies with higher humidity that support pathogens [40]. The trend indicates that severity of mass of diseases is found to be higher with elevated CO_2 levels [41], an off-shoot of climate change.

In general, increased plant density will be likely to increase leaf surface wetness and leaf surface wetness duration, and so make infection by foliar pathogens more likely [42]. Insect herbivore performance is positively correlated with leaf nitrogen concentrations [43]. Plants can also defend themselves mechanically, either by having tough leaves or by structures such as leaf trichomes. The direct effects of high CO_2 on multiple generations of cotton aphid, *Aphis gossypii* were weak, even no existing. Moreover, the impact of prominent CO_2 level on the growth, development and fecundity of *A. gossypii* was mainly not direct; even however the host plants growing under high CO_2 level were directly influence [44]. Levels of leaf sugars were enlarged by 31% at elevated CO_2 and coincide with a major increase in the density of the invasive species, *Popillia japonica*. The amplified level of sugar in leaves grown at high CO_2 may act as a phagostimulant for the Japanese beetle.

According to Prasannakumar *et al*. [45] high CO_2 exhibited positive effect on BPH multiplication and resulted in more than a doubling of its population at peak incidence compared to ambient CO_2. Longer larval life-span for the third generation and lower pupal weight for all generations were observed in *H. armigera* feed on milky grains of spring wheat grown in elevated CO_2. Studies along with the 27 diseases examined under elevated CO_2 levels, 13 caused higher crop losses than estimated. Ten of the diseases had a reduced impact, and four had the same effect as they do now [46].

3.3 Effect of rainfall (precipitation)

Illustrate that the total precipitation did not change pest population, but the frequency of light rain decreased and the occurrence of heavy rainfall increased pest population [47]. Fungal pathogens are favored by high humidity and their incidence would be increased by climate changes that extend periods of high humidity and reduced by those that result in drier conditions. Some insects are susceptible to precipitation and are killed or removed from crops by heavy rains *e.g.* onion thrips are susceptible to precipitation and are killed or removed from crops by heavy rains [48]. For some insects that lie dormant in soil, such as the cranberry insect pests, flooding the soil has been used as a control measure.

One would expect the predicted more common and deep precipitation events forecasted with climate to negatively contact these insects. Other insects such as pea aphid are not tolerant of drought. Studies on brown plant hopper have shown that BPH populations increase with increase in precipitation up to 400 ppm and decrease with a precipitation >500ppm. Sharma [49] observed that delay in onset of monsoons resulted in delayed plantings of pigeonpea that are prone to damage by *Helicoverpa armigera* and caused heavy damage. Droughts are to be expected to decrease multi-trophic range and change the composition of arthropod communities which in turn may affect the other associated taxa. Increased summer rainfall and drought conditions encourage rapid increase in the population of wireworm (*Agriotes lineatus*) in the upper soil. Egg viability of *Scopelosaurus Lepidus* observed under drought condition by Karuppaiah and Sujiyanad [50] and resulted that egg did not hatch under dry conditions.

4. Climate Change and Insect Pest Management

It is usually anticipated that a changing climate and more erratic weather patterns will make pest's attacks more unpredictable and their amplitude larger. With CO_2 levels and temperatures increasing, precipitation becoming more changeable and non-native insect species moving into new array, changes in insect–plant interactions and IPM regimes will be substantive and less expected [51]. Agro-ecosystem change may be that glasshouse pests could become more difficult in open pastures and field. According to Morris [52] population growth and longevity of short-lived species may be superior. Relaxed cold constraint could be one of the key drivers for exacerbating the increase of insect pests into new regions, and a longer growing season in current regions [53].

4.1 Cultural practices

Changing farming and adaptive management tactic will be required to reduce the impact that agricultural pests have on crops [54]. This may contain, planting different plant varieties, variation of sowing date, mulching, raised beds, shelters, protecting crops from heavy rain, high temperature and flooding, preventing soil degradation and increasing the diversity of habitat on edges to encourage natural enemy numbers. At the farm level and the microclimate level, changing farming strategies is most significant. Crop rotation can aid in suppressing diseases, which are predicted to increase in prevalence under a changing climate. For example, planting oilseed, pulse and forage crops within a cereal cropping system disturb disease cycle [55]. Increasing genetic range can also suppress diseases, such as fungal blast occurrence among different rice varieties.

4.2 Predators and Parasitoids

Biological control of insect-pests is one of the important factors of integrated pest management, safeguarding the ecosystem. Natural enemies of crop pest *viz.,* predators, parasitoids and pathogens are rapid density responsive in their action subjected to the action of abiotic components. Being tiny and fragile, natural enemies of the insect-pests are more sensitive to the climatic severe like heat, cold, wind and rains. Precipitation vary can also affect predator, parasite and pathogens of insect-pest resulting in a complex dynamics. With changing climate, incidence of entomopathogenic fungi might be favoured by extended humidity conditions and inflexibly be reduced by drier conditions [56]. Awmack [57] predicted that climate change may increase susceptibility of aphids to natural enemies. Parasitism could be reduced if host populations emerge and pass through susceptible life stages before parasitoids emerge. Hosts may pass though susceptible life stages more quickly at higher temperature, reducing the gap of occasion for parasitism. Some studies suggest that high temperature increase the possibility that a host will kill its parasitoid. For occurrence parasitism of the caterpillar *Spodoptera littoralis* by the parasitoid, *Microplitis rufiventris* is less efficient at 27 °C than at 20 °C [58]. Parasitoid populations may also be disrupt by severe events and variable climate. There may also be spatial and temporal mismatches between pests and their natural enemies which will reduce the efficacy of biocontrol agents and predicting these impacts will be difficult without a thorough understanding of the tritrophic interactions among species [59].

4.3 Pesticides

Since the 1960s, there has been a 15-20 double increase in pesticide use. Additionally, as crop yield has enlarged, due to the use of high yielding varieties, soil and water management, fertilization and cultivation methods, there has been a raise in crop loss due to pest. Many new varieties of crops are more dependent on pesticides as they have lower tolerance to competitors and herbivores, as much of the inbuilt resilience is bred out [60]. Pesticide applications are the primary method of managing pests in the industrialized world. The application of pesticides is associated with temperature at sites and site minimum temperature can provide as an alternate for pesticide application. For example, Ziska [61] assessed pesticide applications on soybean along a 2100 km latitudinal gradient in the USA and found that soybean yield did not differ over the gradient, even as total pesticide application increased from 4.3 kg ha^{-1} active ingredient in Minnesota (having a minimum daily temperature of -28.6 °C) to 6.5 kg ha^{-1}active ingredient in Louisiana (-5.1 °C minimum daily temperature). With a changing climate, herbicide use will increase in the other temperate regions, whereas there will be a greater increase in insecticide and fungicide utilize closer to the tropics. This is due to the fact that, in temperate regions, warming enhances growth and insect reproductive output, as well as survival [62].

4.4 Semiochemicals

The signaling chemicals which cause changes in the behavior of other living organisms [63] play a vital role in IPM. The use of pheromones and allelochemicals is a key method that insect use to intellect their environment. Their use in monitoring, trapping, mating disruption, push pull strategies and biological controls makes them perfect for a range of IPM techniques [64, 65]. Temperature, humidity and air speed can have serious impact on the effectiveness of semiochemicals. According to Cork *et al*. [66] used PVC resin controlled release formulations to deliver sex pheromones to the yellow rice stem borer at a range of temperature (from 22 °C to 34 °C). The temperature used highly influenced pheromone rates, with half lives of the sex pheromone decreasing with an increase in temperature. Temperature has also been shown as the critical environmental variable influencing volatile release rates in moth sex pheromones [67], light brown apple moth pheromones [68]. At high temperature, aphids have been exposed to be less responsive to the aphid alarm pheromone they release when under attack by insect predator and parasitoids resulting in the possible for greater predation [69].

4.5 SIT Technique

The sterile insect technique (SIT) is an important method used to control insects [70] which release radiation induced sterile males into wild populations to reduce the number of offspring after mating with wild females. It is a key method used to control *Ceratitis capitata* (Tephritidae: Diptera) worldwide [71]. One of the strains of *C. capitata* has a temperature sensitivity gene, *tsl*, which makes the homozygous female embryos susceptible to high temperature mortality (compared to males) after 24 hours of development [72]. Females remain susceptible to temperature throughout their lifetime, but the impact of the *tsl* gene mutation or the effects of irradiation on released males in the field are currently unidentified [73]. This advantage of lab reared sterile males could increase their usefulness as a pest management tool under a warming climate.

5. Future Research

Agricultural impact assessment based on changing yield due to increased pressure from pest due to climate change is still in its infancy. However, it is clear that human induced climate change will have impact on all feature of IPM system, pest outbreak, pollinator synchrony with flowers, efficiency of crop protection technology, parasitoid and predator efficiency [74]. For IPM to be accepting more fully within cropping systems, regimes that increase management tactic flexibility, such as those outlined by Nash and Hoffman [75], need to be implemented. This requires a greater understanding of pest population dynamics, thermal physiology, ecology, behaviour and hub IPM priorities [76, 77].

In addition to the strategies we require to decide the future research on breeding climate-resilient varieties, rescheduling of crop calendars, GIS based risk mapping of crop pests and screening of pesticides with novel mode of actions. Geographic information systems (GIS), global positioning systems (GPS) and remote sensing (RS) are allied technologies that together provide a means of gathering, integrating and analyzing spatial data. How climate changes will affect development, incidence and population dynamics of insect-pest can be studied through GIS by predicting and mapping trends of probable changes in geographical distribution [78] and delineation of agro-ecological hotspots and future areas of pest risk [79]. To date, the application of these tools within traditional and area wide programmes have been relatively limited, but this seems likely to change, particularly as GIS and GPS are already being used extensively in other areas of agro ecological management and research.

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