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A BRIEF OVERVIEW OF THE RELATIONSHIP BETWEEN GLOBAL WARMING AND INSECT OUTBREAKS

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Abstract: Climate change can influence insect outbreaks in various ways. Warmer temperatures can accelerate insect development and reproduction rates, leading to population booms. Increasing temperature, rising CO_2 concentration and the change in rainfall are favourable conditions for pest outbreaks. These lead to changes in insect diversity, abundance, population growth rate and biotic interactions resulting in more severe economic losses in agriculture. In addition to biological control techniques, under such sudden weather and climatic fluctuations, the effectiveness of chemical control would also be in doubt in future IPM programmes.

Keywords: Climate change, Entomological aspects, Global warming, Insect pests, IPM.

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INTRODUCTION

Increased population development has resulted in a steady rise in the need for agricultural production, putting global food security at risk. Meteorological components at the field level affect the quality and quantity of agricultural goods. Climate events such as storms, droughts, floods, elevated carbon dioxide (eCO_2), changing precipitation, and rising temperatures all have a substantial impact on food supply. The climate change is a big worldwide concern that affects all the aspects of agriculture and sustainable development (Verma, 2021; Ambasht, 2022).

The Intergovernmental Panel on Climate Change (IPCC) defines 'climate change' as 'a change in the state of the climate that can be identified by changes in the mean and/or variability of its properties, and that persists for an extended period, typically decades or longer' (IPCC, 2023). Climate warming is projected to lead to the extinction of 15-37% of species by 2050 (Hance *et al*., 2007). Crop plant development increases the geographic spread of tropical and subtropical insects (Gonzalez and Bell, 2013; Sharma, 2014).

Global warming may expand the geographic range of insects, leading to greater transmission of insect-borne plant diseases. The effects of some of the expected climate changes will be reviewed in this article, with particular attention made to the rise in temperatures and atmospheric carbon dioxide concentrations as well as the implications of variable precipitation patterns. Examines the ecosystem and biology of dangerous insects, particularly invasive pest species, can pose a significant threat to crop yields.

IMPACT OF CLIMATE CHANGE ON CROP PESTS

Both agriculture and agricultural insect pests are significantly impacted by changes in the global climate (Skendžić *et al.,* 2021). Climate change has an impact on agricultural crops and the pests that prey on them, both directly and indirectly. The indirect effects of climate change are those on the associations that pests have with their surroundings and other insect species, including natural enemies, rivals, vectors, and mutualists. Direct effects are those on the reproduction, development, survival, and dissemination of pests (Prakash *et al.*, 2014).

Since insects are poikilothermic creatures hence the environmental temperature affects the temperature of their bodies. As a result, temperature is most likely the environmental element influencing insect behaviour, dispersal, growth, and reproduction. The population dynamics of insect pests and, thus, the percentage of crop losses could be considerably impacted by the primary drivers of climate change, which are rising atmospheric CO_2, rising temperatures, and decreasing soil moisture (Fand, 2012).

Response of Insects to increasing temperature

The physiology of insects is highly sensitive to temperature variations; on average, a 10°C increase in temperature causes their metabolic rate to roughly double. In this regard, numerous studies have already demonstrated that rising temperatures typically hasten the consumption, growth, and migration of insects. These effects can then have an impact on population dynamics through changes in fecundity, survival, generation duration, population size, and geographic range. Some species can flourish and procreate quickly, while species that are unable to evolve and adapt to warmer temperatures typically struggle to sustain their populations. Temperature affects the motility, metabolism, metamorphosis, and host availability, all of which impact the likelihood of alterations in the dynamics and population of pests.

As an example, aphids, for instance, are less vulnerable to the aphid alarm pheromone that they typically emit in response to insect predators and parasitoids in warmer climates, which may result in a rise in predation (Bale *et al.,* 2002; Singh *et al.,* 2023). Environmental elements including general humidity, temperature, and precipitation have a major role in controlling whitefly populations. Increased whitefly populations are positively correlated with high temperatures and high humidity (Pathania *et al.,* 2020).

Reaction of Insect Pests to Rising CO_2 Concentration

The distribution, quantity, and behaviour of herbivorous insects can all be effected by increased atmospheric CO_2 concentrations. The consumption, growth, fertility, and population densities of insect pests can all be influenced by such increases (Coviella and Trumble, 1999). The way that rising CO_2 levels affected insect pests depends largely on the plants that serve as their hosts. C3 crops (wheat, rice, cotton, etc.) would be more affected by higher CO_2 levels than C4 crops (corn, sorghum, etc.). Thus, asymmetric effects on herbivory and a different reaction from insects feeding on C4 plants compared to C3 plants could arise from these differential effects of high atmospheric CO_2 on C3 and C4 plants. While C4 plants are less sensitive to elevated CO_2 and hence less likely to be affected by changes in insect feeding behaviour, C3 plants are likely to be positively affected by increased CO_2 and negatively affected by insect reaction.

Despite several studies undertaken to examine aphid responses to rising atmospheric CO_2 levels, it is still impossible to forecast future responses in general or create general principles for diverse aphid populations in response to climate change.

The impact of changing rainfall patterns on insect infestations

Climate change makes planting time more uncertain. A 45-days delay in the start of the monsoon during the 2009 rainy season led to a delay in the planting of pigeon peas, which are vulnerable to *Helicoverpa armigera* damage and resulted in significant damage (Sharma, 2010). Variations in precipitation can have an intricate effect on parasites, illnesses, and insect pest predators, similar to temperature variations. Insect fungal pathogens thrive in high-humidity environments, hence climate changes that prolong high-humidity periods will increase their occurrence, while those that result in drier circumstances would decrease it. It is crucial to take this into account when selecting management strategies for onion thrips because certain insects are precipitation-sensitive and might be destroyed or driven out of fields by prolonged downpours.

Increased overwintering survival

Since insects are cold-blooded, poikilothermic creatures, their ability to maintain homeostasis in response to temperature fluctuations is restricted. To survive in environments that are thermally challenging, they have developed a number of survival mechanisms. In general, insects can be divided into two groups based on how they overwinter: those that tolerate freezing temperatures and those that avoid it. While the second group of insects utilises behavioural avoidance or migration as a tactic, the first group uses diapauses as a physiological adaptation (Taylor, 1986).

Diapause is a hormonally mediated state of low metabolic activity that can occur in insects and is defined by inhibited development, halted activity, and greater resilience to harsh environmental conditions. Diapause is an adaptive characteristic that is controlled by temperature, photoperiod, and humidity. It is crucial to the seasonal regulation of insect life cycles. Adult European bluebottle flies, for instance, raise less diapausing offspring when raised at 20°C. Additionally, the diapause is shorter than in flies raised at 15°C. Higher temperatures are necessary to let the next diapausing generation mature before harsh winter conditions start when diapause is necessary for successful overwintering. Although the timing of bud burst is unlikely to change significantly with a 2°C increase in temperature, the timing of larval hatching is likely to be significantly advanced. This could result in larval hatching before bud bursts, which is dangerous for the moth and could lessen this particular pest problem (Harrington *et al.*, 2001).

Threat of Invasive Alien Insect species growth

A taxonomic species is considered an invasive alien species (IAS) if it is introduced accidentally by human activity outside of its natural habitat, or purposely (e.g., food, crops, ornamentals, pets, cattle). Insects that are considered invasive are typically found in agriculture, forests, stored products, homes, or buildings. They can also act as carriers of parasites or bacteria. International travel, the world trade system, and agriculture have all contributed to the exponential acceleration of the spread of species over the past millennium to areas outside of their native range (Ricciardi, 2013).

For alien insects to become invasive, they must be able to settle into a new environment, endure there, and flourish. Climate change may have an impact on this invasive pathway's constituent parts in both good and harmful ways.

The climate, in conjunction with topographical characteristics, establishes the boundaries for the spread of these species and establishes the seasonal conditions necessary for their maturation, proliferation, and endurance in a novel environment. These habitats may have been unsuitable in the past, and a geographic barrier, like mountain ranges or the sea, may have prevented dispersal to appropriate, distant habitats (Vanhanen, 2008).

Effect of Climate on Pest Population via Natural Enemies

Changes in plant nutrition can cause herbivore development times to increase, which might increase herbivore prey's susceptibility to predators by giving predators a longer window of opportunity to feast on them. *Galerucella lineola* F. (Coleoptera: Chrysomelidae), a willow-feeding leaf beetle, develops differently on different hosts; in those where development is prolonged, there is a larger chance of predation by a variety of taxa, such as spiders and predatory bugs belonging to

Pentatomidae and Nabidae. Variations in the host's development can also affect the activity and fitness of parasitoids; longer development times render hosts more vulnerable to parasitism, especially if they expose parasitoids to host instar stages that are comparatively more vulnerable to parasitism. Beneficial plants may alter the expression of volatile organic chemicals and secrete extrafloral nectar in response to insect feeding, both of which are known to offer protection against herbivores (Heil, 2008). Under climate change, temperature increases may have an impact on the synthesis and release of volatile chemicals.

Effect on Pollinators

Temperature increases may have an effect on plant phenology and pollinator behaviour. One way that many plant species have adapted to the increased temperatures is through early blossoming. In general, plants pollinated by insects react more severely to rising temperatures than plants fertilised by the wind. Plant species that bloom early in the season seem to be the most sensitive (Pudasaini *et al.*, 2015). Because of plant phenology changes, new species invasions, extinctions, and changes in pollinator composition brought on by global warming, pollinator activity will be out of whack. Tropical insects are more susceptible to the negative impacts of global warming than their temperate counterparts because of their low heat tolerance, even though temperature rises in tropical places are not as great (Deutsch *et al.*, 2008).

Outbreaks in Recently Invaded Geographic areas

The distribution range of the pine processionary moth *Thaumetopoea pityocampa* (Denis & Schiff.) has grown in recent decades, both latitudinal and elevation (Battisti *et al.*, 2005). Increased survival during the winter feeding season has fuelled outbreaks in France, Italy, Spain, and Turkey's previously uninhabited pine forests. Warm summer evenings promote the long-distance (greater than 2 km) dispersal of female moths, allowing for rapid range extension (Battisti *et al.*, 2006). While damage and death of plants become visible during outbreaks, bark beetle species linked to weaker trees are typically hard to spot at low levels. As a result, the epidemic range is typically taken into consideration, but the boundaries of the endemic range are still mostly unknown. Warmer winters in the southeast of the United States have caused the southern pine beetle, *Dendroctonus frontalis* Zimm., to shift its distribution northward (Ungerer *et al.*, 1999).

STRATEGIES FOR PEST MANAGEMENT: ADAPTATION AND MITIGATION

There will be more uncertainty and occurrences of both new and old pests due to climate change and the acceleration of global trade. Therefore, it will be even more crucial to increase one's capacity for quick adaptation to disruptions and climate change. It is now possible to lessen the harmful effects of current pests and lower the likelihood of future illnesses and pests spreading. Numerous adaption solutions have been identified. Monitoring temperature and insect pest populations, using modelling prediction tools, and modifying integrated pest management (IPM) methods are the most often recommended strategies.

Monitoring

Monitoring is the backbone of IPM. Detecting invasive species is crucial for monitoring, particularly in light of climate change. Invasive species can lead to the extinction of threatened and endangered species, alter the organisation of terrestrial and aquatic communities, and reduce overall species diversity.

Detection of Changes in Insect Distribution

Given that insect distribution is predicted to be significantly influenced by climate change, it is critical to identify any potential change in species distribution ranges in order to effectively manage them. In these kinds of investigations, generic modelling tools like Bio Sim and Climex have shown to be helpful. Utilising existing data regarding a species' reactions to significant climate variables, Bio Sim forecasts a species' possible geographic range and reproductive success.

Pest Forewarning

Reliable medium-range weather forecast can help in proper timing of crop management practices such as sowing, irrigation, fertilizer application and pesticide application. This would increase efficiency of crop production and protection technology. Likewise, pest forecasting can help in cautioning farmers about impending pest situation and adoption of preventive measures to avert pest problems.

Cultural Control

Reducing the effect of agricultural pests on crops will necessitate farming changes and the use of adaptive management techniques. This could entail: (1) growing various plant species; (2) planting at various seasons to reduce exposure to insect outbreaks, and (3) broadening the range of habitat types along boundaries to encourage the presence of natural enemies. At the farm level, all of these tactics are employed to reduce the impact of pests. Mulching, raised beds, and shelters to retain soil moisture, shielding crops from intense rains, extreme heat, and flooding, and stopping soil degradation are some reasonably easy techniques. Adapting new farming practices is especially important at the farm and micro-climate levels; however, pollution and other anthropogenic activities also play a role (Prakash and Verma, 2022; Singh *et al.,* 2023).

Crop Rotation and Diversification

Crop rotation can assist 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 disrupts disease cycles. Increasing genetic diversity can also suppress diseases, such as fungal blast occurrence among different rice varieties. Disease-susceptible rice varieties exhibited an 89% yield increase in the Yunnan Province of China when planted in mixtures with resistant varieties, and rice blast (the major disease of rice) was reduced by 94% (Zhu *et al*., 2000).

Biological Factors

Methodologically, the most assessments of parasitoids and predators have been done at constant temperatures. Bahar *et al*. (2012) found that fluctuating temperatures in laboratory conditions (particularly lower temperatures) can substantially change the developmental period of pest herbivores (in their case the diamondback moth) and its parasitoids.

Semi Chemicals

A key component of integrated pest management (IPM) is the signalling chemicals, or semi-chemicals, that alter the behaviour of other living things. An important technique used by insects to sense their surroundings is the use of pheromones, which act between members of the same species, and allele chemicals, which act between species and include kairomones that benefit the recipient, emitter or both. These are perfect for many IPM techniques because of their use in biological controls, push-pull tactics, monitoring, trapping, and mating disruption. Additionally, it has been well demonstrated that temperature has a crucial role in determining the rates at which volatiles released from light brown apple moth pheromones, moth sex pheromones, tsetse fly kairomones, and waterbuck odours that suppress tsetse fly populations (Shem *et al*., 2009).

Reproductive control

A vital tool for managing insects is the sterile insect technique (SIT), which introduces radiation-induced sterile males into natural populations to lower the amount of progeny following mating with natural females. Globally, it is a very significant strategy for managing *Ceratitis capitata* (Wied.) (Tephritidae: Diptera) (Robinson, 2002). A temperature sensitivity gene called tsl is present in one strain of *C. capitata*, and after 24 hours of development, homozygous female embryos are susceptible to high-temperature mortality (in comparison to male embryos). Throughout their lives, females are temperature-sensitive, but it is currently unknown how the tsl gene mutation or radiation exposure affects released males in the field. In South Africa, population density decreases as temperatures drop below minimum essential temperatures and increases after an adequate number of degree days have accrued. According to their higher critical temperature maximum and longer field lifespan than wild-type individuals, individuals carrying the tsl mutation suggest that the sterile insect approach might be more successful in a warmer climate.

Pesticides

Since the 1960s, the production of maize, wheat, and rice has doubled globally, but the use of pesticides has increased by 15-20 times with several bad effects on animals (Oerke, 2006; Prakash and Verma, 2014). Furthermore, there has been a rise in crop loss from pests as crop output has increased because of the adoption of high-yielding cultivars, proper soil and water management, fertilisation, and cultivation techniques. Since most of the natural resilience has been bred away, many new crop types are more dependent on pesticides because they are less tolerant of herbivory and competition (Oerke, 2006). It is expected that the use of a variety of pesticides will be one of the more sought-after management tools due to the increased likelihood of insect pest outbreaks and the need for a 50% increase in global food production to meet the needs of the world's population by 2050 (Chakraborty and Newton, 2011). The main approach to controlling pests in the industrialised world is the application of pesticides. The temperature at a location is related to the application of pesticides, and the minimum temperature at a site can be used as a stand-in for pesticide application.

Directions for Future Research

Under a changing climate, insect pests are likely to become more damaging, especially if the current worldwide broad-spectrum spraying regimes continue. For IPM to be adopted more fully within cropping systems, regimes that increase management strategy flexibility, such as those outlined by Nash and Hoffmann (2012), need to be implemented. This requires a greater understanding of pest population dynamics, thermal physiology, ecology, behaviour and core IPM priorities of host plant resistance, area-wise management, emergency chemical control when required, and predictive modelling tools when controlling pests in a more variable climate.

Managing insect pests in agriculture in a rapidly changing climate will require a broader approach that incorporates a variety of management strategies, such as the use of resistant cultivars, pheromones, selective insecticides rather than broad-spectrum pesticides, tillage management, crop rotation, and biological controls (natural enemies). To address this challenge, climate-smart pest management (CSPM) approach has been developed. It provides more focus on the management of various plant pests in the context of climate change and involves all key actors in the production chain: farmers, research institutes, advisory services, and governmental bodies.

CONCLUSION

It is generally acknowledged that climate change has a significant impact on the production of agricultural plants and the insect pests that are linked with them, even though there are still many unanswered questions about it. Some of the uncertainties surrounding various components of climate change that are pertinent to insect pests include small-scale climate variability, such as changes in relative humidity, temperature, atmospheric CO_2, and precipitation patterns. Insect species are likely to respond differently to global warming depending on where they live in the world due to the great diversity of these creatures, the plants that serve as their hosts, and the fluctuations in the worldwide temperature. The impacts of climate change on insects are multifaceted, affecting their distribution, diversity, abundance, development, and growth while favouring certain insects and hindering others. If climate change variables provide better conditions for pest infestation and agricultural destruction, there may be a big risk of economic losses and a threat to human food security. In order to minimize these losses, proactive and scientific approaches including planning and developing adaptation and mitigation techniques such as improved IPM approaches, climate and pest monitoring and the use of modelling tools are highly recommended.

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