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Insect pests under changing climate and climate-smart pest management

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Abstract
A significant problem for agriculture globally is climate change, via its effects on the distribution, biology and potential of spread of diseases and pests in all ecosystems, climate change is already having an effect on agriculture. Climate change influences the distribution and severity of crop pests, i.e., " any animal, plant or pathogenic species, strain or biotype harmful to plants or plant products" directly and indirectly. Upto 40 per cent of the world's food supply is already endangered by pest and the decrease in pest impact is of prime concern than ever for ensuring global food security, reduction in greenhouse gas emissions and decreased application of inputs. Climate-smart pest management (CSPM) is a multi-sectoral strategy aimed at reducing crop losses caused by pests, improving ecosystem services, reducing the level of greenhouse gas emissions per unit of food produced and enhancing the resilience of agricultural systems to climate change. CSPM should not be understood as a stand-alone solution in order to be successful, but as part of a larger CSA (Climate Smart Agriculture) intervention that considers pest management to be one of its main components. Effect of climate change is more in temperate insects which affect their range expansion, host enemy synchrony and interspecific competition. CSPM strongly stresses the need to establish and introduce more reliable diagnostic techniques to classify pests and their natural enemies in order to be able to make decisions on pest control in the future. Since, climate change is because of human activities and can also be minimized by human activities. Therefore, there is a need to look after the effects of climate change on crop protection and ultimately safeguard food security.

Keywords: Climate, crop protection, ecosystem, food security, natural enemies

Introduction
In order to meet the needs of the increasing world population and their evolving diets, the FAO predicts that global food production would need to increase by 60% by mid-century (Alexandratos and Bruinsma, 2012) [1]. A significant problem for agriculture globally is climate change, via its effects on the distribution, biology and disease potential of pests in ecosystems, climate change is already having an effect on agriculture. The production of crops has been significantly affected by dynamic climatic parameters, including elevated temperature and carbon dioxide, change in rainfall patterns etc. These changes are primarily due to the overexploitation and abuse of natural resources, such as increased urbanisation, deforestation and industrialization, for various anthropogenic developmental activities. Climate change often directly and indirectly influences the distribution and severity of crop pests, i.e., "any animal, plant or pathogenic species, strain or biotype harmful to plants or plant products" (FAO, 2013) [13]. There is an increase in the number of insect pest species, insect breaks, an increased number of generations per year and the production of resistant biotypes due to climate change. Climate change has a detrimental effect on the ecosystems of natural enemies. The overall food production mechanism that could be at critical risk from the effects of climate change may also be manipulated by this (Yadav *et al.*, 2019) [36]. The bulk of the warming that has been observed over the last 50 years is due to human activity. From 1990 to 2100, the global mean surface temperature is expected to rise by 1.4 to 5.8 °C. For the next 100 years, if temperatures rise by around 2 °C, the detrimental effects of global warming on most regions of the world will begin to increase. The temperature in India has risen between 0.2 °C and 1 °C (IPCC, 2001) [18]. Both plant and herbivore phenology may be altered by elevated temperatures with a probable impact on synchronisation between the two, again indirectly affecting the behaviour of natural enemies and the efficacy of their natural control.

In temperate regions, higher minimum temperatures can result in the expansion of the geographical range of insect pests that are currently intolerant to low temperatures. If natural enemies fail to track and pursue their hosts, this can result in pest outbreaks in the newer areas. The variability in precipitation is reported to have an adverse effect on the degree of parasitism of several caterpillar pests. Less prone to climate change impacts are sucking pests such as cereal aphids. In the case of mealy bugs, parasitism is apparently reduced due to enhanced immune response under conditions of water stress associated with drought conditions (Prasad and Bambawale, 2010) [27].

Impact of increased temperature on insect pests

Insects being exothermic are more active under warmer conditions. According to Yamamura and Kiritani, 1998 [37]., it is predicted that with every 2 °C increase in temperature, insects might experience one to five additional life cycles. For example, Williams *et al.,* 2003 [35] observed increased gypsy moth performance with increase in temperature because of decrease in development time and subsequently increase in survival time. This means if gypsy moths would favourably react to future environments than competitors, they might become more prone to outbreak. Gender ratios of some pest species such as thrips might change as a result of change in increased temperature by affecting reproduction rates (Lewis, 1997) [23]. Change in the winter temperature may reduce the rate of mortality percentage because of warmer winter which could be one of the important factors of increasing insect pest populations (Harrington *et al.,* 2005). With increase in latitude and altitude, insect species diversity per area tends to decrease (Andrew and Hughes, 2005) [4], which means more insect species will attack more hosts in temperate climates because of rising temperatures (Bale *et al.,* 2002) [7]. Kingsolver *et al.,* 2011 [19] observed influence of increasing temperatures on the feeding and growth rates and adult reproduction, the insect pest ontogeny, preventing survival to maturity. The changes in temperature can have negative impacts on some insect species, but for other it could be beneficial or no effect at all depending upon the role of insect in plant, animal and human health (Sharma, 2010; War *et al.,* 2016) [30]. Indirect effects also occur at higher levels of the food chain, such as changes in abundance and development period of predators, pathogens and associated micro-organisms.

Impact of changing precipitation pattern

According to Hatfield *et al.,* 2011 change in precipitation pattern whether excessive or insufficient can have substantial effects on crop-pest interactions as most of the species are favoured by warm and humid conditions. Increase in frequency and severity of precipitation may result in the potential outbreak of locust pests in the future. In western and northern Africa, changes in precipitation followed by heavier rains resulted in the outbreak of desert locust in 2004 which caused significant losses and food shortages (Masters and Nargrove, 2010). It is being predicted that due to climate change, rainfall frequency would decline but its intensity would increase. This would increase the severity of certain crop pests and ultimately threaten our food security. Favourable weather conditions such as heavy rainfall followed by dry spell can contribute to the outbreak of *Spodoptera litura* (Chari *et al.,* 1993). Water availability strongly affects the crop production. Under climate change, rainfall patterns, soil moisture content and evaporation are likely to get affected which inturn directly or indirectly affect the insect pest population (Skendzic *et al.,* 2021). Heavy rains and dry spells may lead to the outbreak of red hairy caterpillar and cutworms respectively (Sardana and Bhat, 2016) [28].

Impact of increased Co_2 levels on insect pests

Since, global co_2 concentrations rose rapidly since the industrial revolution and are considered as a primary factor in climate change (Sun *et al.,* 2011) [33]. Carbon dioxide may profoundly affect crop-pest interactions. It is evident from the rise in Co2 levels that farmers can expect to face new and severe insect pest problems in the coming years under climate change (Skendzic *et al.,* 2021). Sun *et al.,* 2011 [33] observed significant effect of elevated co_2 levels on insect herbivores and their natural enemies. Elevated co_2 delayed growth and development of chewing insects by decreasing the food quality of host plant. However, aphid species were successful under increased co_2 levels (Sun *et al.,* 2011) [33]. *Spodoptera litura* has been emerging as a serious pest under high levels of co_2 (Kranthi *et al.,* 2009) [20]. Carbon to nitrogen ratio of plant tissues generally increases with increase in carbon dioxide levels in the atmosphere (Deka *et al.,* 2009) [10]. Increase in carbon to nitrogen ratio in the plant tissues (Ainsworth *et al.,* 2002) results in the decrease in nutritional quality for protein limited insects diluting the nitrogen content of the tissues (Coviella *et al.,* 1999) [8]. There are many major pests that result in the emission of Co2 and become contributors of global warming like bugs and termites. Termites after consuming wood result in the emission of Co2 after digestion (Sugimoto *et al.,* 2000) [32]. The lifecycle of bugs become shorter with increase in each degree of global warming. Goverde and Erhardt (2003) [15] observed changes in the nutrient content of the plants resulted in longer days for the development of larvae and plants gave different reactions on the change in co2 content which can affect host plant selection in the future. Eigenbrode *et al.,* 2015 [12] reported that predators and parasites become more efficient at higher co2 levels in controlling different pests.

Climate-smart pest management (CSPM)

Climate-smart pest management (CSPM) is a cross-sectoral strategy aimed at reducing crop losses caused by pests, improving ecosystem services, reducing the level of greenhouse gas emissions per unit of food produced and enhancing the resilience of agricultural systems to climate change. The introduction of the CSPM definition makes it possible to manage more effectively the increased threat to agricultural production and ecosystem services posed by new and existing crop pests, and thus increases the resilience of farmer's livelihoods and overall local and national food security to climate change (Fig. 1). By improving the overall greenhouse gas (GHG) balance, CSPM also contributes to climate change mitigation; reducing pest-related yield losses, for instance, reduces the intensity of GHG emissions per unit of food produced. CSPM will directly contribute to a reduction in emissions per unit of food produced by reducing avoidable yield losses, thus reducing the overall GHG emission intensity of these systems. CSPM should not be understood as a stand-alone solution in order to be successful, but as part of a larger CSA intervention that considers pest management to be one of its main components. CSPM will provide farmers with the knowledge and resources available to quickly and proactively introduce pest prevention practises (e.g. crop diversification, construction of natural habitats and careful management of water) that will improve the health of their farms and the surrounding environment and minimise vulnerability to disruption caused by pests. Increasing crop diversity by intercropping is an easy and efficient activity that provides benefits in reducing the density and severity of the disease and pest population (Li *et al*., 2009; Ding *et al*., 2015). Intercropping has proven to be easy and reliable, ecological strategy that changes the local environment and promotes decreased pest pressure and increased activity of natural enemies. Correctly assembled crop diversification in time and space, a significant ecological role is played in promoting natural interactions with plant insects that promote crop defence. (Markovic, 2013) [24]. Similarly, Habitat management is an important pest control technique for integrated pest management (IPM). For several years, different categories of habitat management have been used in applied insect ecology, such as trap cropping, intercropping, natural enemy refuges such as 'beetle banks' and floral tools for parasitoids and predators. (Gonzalez-Chang, 2019). It is not the sole duty of the farmer to guarantee that CSPM operates effectively. In certain cases, farmers do not have the resources they need to be able to make educated decisions about proactive and reactive pest management. CSPM strongly stresses the need to establish and introduce more reliable diagnostic techniques to classify pests and their natural enemies in order to be able to make decisions on pest control in the future (Lamichhane *et al*., 2016) [21]. Farmer cannot take decisions alone, extension agencies, other research institutes, public and private agencies help the farmer to choose among many options. CSPM tries to ensure that the management of pests is ready to either avoid or resist pests coming into a region and control certain populations that are rising in numbers. As this has been shown to improve the resilience of agro ecosystems to the impacts of climate change, CSPM can work proactively to increase the level of biodiversity across their farm and surrounding landscape. (Altieri 2012, Altieri *et al.*, 2015) [3]. CSPM aims to increase the resilience of farmers by developing a climate-responsive national extension system and by establishing working ties between science and technology and farmers as a means of overcoming the systemic disconnection between research and end-users. Therefore, CSPM encourages organised research and extension support and recommends practices and methods to ensure that the services offered by it are proper, available to all farmers, including those who are often neglected. For the success of CSPM, certain CSA activities, such as integrated soil fertility management, site-specific nutrient management, climate-resilient crop breeding, conservation agriculture or crop diversification strategies, are most important. (Heeb *et al.*, 2019) [17]. In addition, farmers will be able to proactively recognise and enforce specific pest prevention practises through climate and monitoring of pests, in combination with pest and climate risk forecasting information, to avoid the build-up and/or appearance of expected pest problems (Agrhymet, 2013).

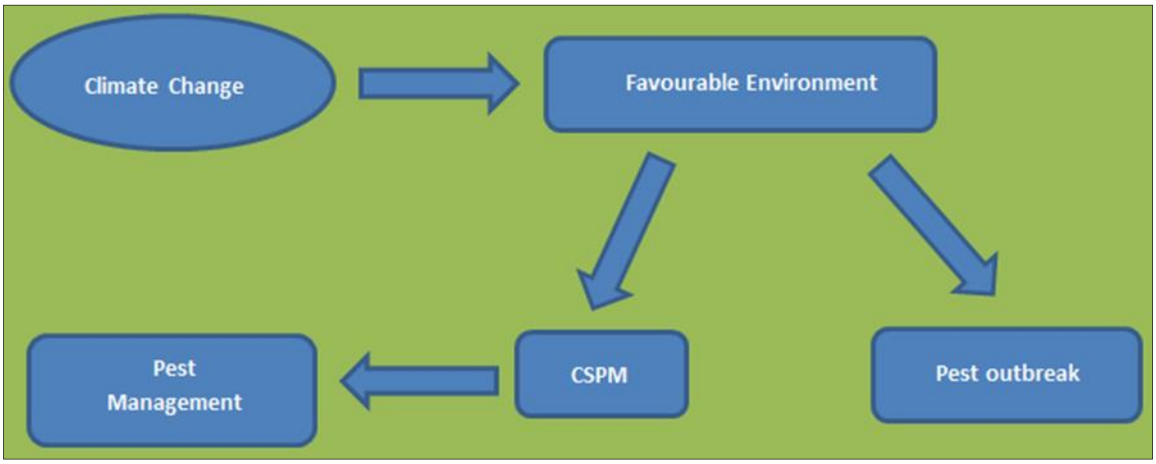

Fig 1: Climate change and climate smart pest management (CSPM).

Prediction of future pest outbreaks

In the 21st century, agriculture is facing huge challenges of meeting food demands of increasing population and now this challenge has been further burdened by increasing crop pests. The distribution of crop pests has become more prevalent due to climate change. The main consequence of climate change is high predictability of spatial and temporal interactions between weather, cropping systems and pests (Lamichhane *et al.*, 2014) [22]. There are chances of sudden outbreak of pests from tropics and sub tropics to temperate regions resulting in the increased abundance of tropical insect pest species (Das *et al.*, 2011) [9]. *Helicoverpa armigera* might disperse in northern India on pulses, cotton and vegetables (Sharma *et al.*, 2010) [29]. Seeing the physiological and ecological impact, some species might get adapted to warmer climates and become major pests. Disruption of synchronization in phenology of insects, host plants or natural enemies occurs due to changes in temperature (Dillon *et al.*, 2010) [11]. Overwintering survival increases within this century where temperature is expected to increase by 1-5 °C (Arora and Dhawan, 2013) [6]. With the increase in temperature, faster depletion of stored nutrient resources occur by which the metabolic rates might shorten the duration of insect diapause (Sharma *et al.*, 2010) [29]. The number of generations might increase with increase in temperature e.g Rice stem borer *Chilo suppressalis* (Walker) would produce two generations per year after 2 °C warming in Japan (Morimoto *et al.*, 1998) [25]. As predicted by Rao *et al.*, 2014 predicted completion of generation of tobacco caterpillar, *Spodoptera litura* would be 5-6 days earlier in Gujarat in near future (2021-2025). Natural enemy populations and their per capita availability is regarded as one of the successful biological controls to locate attack and process prey. Since, climate change may directly or indirectly affect the behaviour and physiology of natural enemies as wee as prey altering the effectiveness of biological control. It has been found that highest prey attack and intake rates occurred when temperature were around 24-26 °C respectively (Nayak *et al*., 2020) [26].

Conclusion

Climate change is already impacting agriculture, including effects on the distribution, biology and outbreak potential of pests across all land uses and landscapes. Because of world's second largest emitter of greenhouse gases, agriculture is a major climate change driver. Doubling of global food production to meet demands of increasing population will be a greatest challenge in the coming century. Therefore, understanding how climate change will impact on various crop pest will help researchers to orient their research on various futuristic possibilities resulting in the mitigation of the menace of anticipated climate change. Temperate insects have more impact of climate change which affect their host enemy synchrony, range expansion and interspecific competition. Climate change has adverse effect on potential of natural enemies which could be a huge concern in outcoming pest management programs. Since, climate change is because of human activities and can also be minimized by human intervention. Therefore, there is a dire need to see the effects of climate change on crop protection and ultimately safeguard food security.

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