International Journal of Ecology and Environmental Sciences
www.ecologyjournal.in
Online ISSN: 2664-7133; Print ISSN: 2664-7125; Impact Factor: RJIF 5.28
Received: 17-10-2020; Accepted: 02-11-2020; Published: 16-11-2020
Volume 2; Issue 4; 2020; Page No. 579-584

Impact of climate change on insect pests and their natural enemies

Sudhanshu Bala Nayak[1*], Kavadana Sankara Rao[2], V Ramalakshmi[3]
[1, 3] Assistant Professor, MSSSOA, Centurion University of Technology and Management, Paralakhemundi, Odisha, India
[2] Senior Research Fellow, ICAR-Indian Institute of Maize Research, Rajendra Nagar, Hyderabad, India

Abstract

Climate change along with rapidly increasing population, depletion of natural habitats and resources would have direct impact on livelihoods and raising concerns for food security, water supply, health and energy. Climate change, an emerging global concern have serious threats in every aspects of agriculture. Changed patterns in climatic factors like temperature, precipitation, humidity and other meteorological components are affecting the quality and quantity of agricultural commodities production. Along with direct impacts in crop productivity, climate change is threatening global food production via pest related losses of food crops. Being poikilothermic, insects are the organisms that most likely to respond to changes in climate, and It is anticipated that the damage to agricultural crops by insects will increase as a consequence of climate change. It has increased pest population and their damage potential by expanding distribution, enhancing survivability and allowing to develop the adaptability of insect pest. Rising temperature, modified precipitation patterns, disturbed gaseous composition of atmosphere etc. are causing the change in population, mobility, behaviour of insect pest.

Keywords: Vernal keratoconjunctivitis, tacrolimus, immunomodulators, olopatadine

Introduction

Recently changing climatic scenario has gained the attention of scientific community significantly all over the globe, threatening the all forms of life on earth. Continuous release of greenhouse gases (GHGs) such as carbon dioxide, methane, nitrous oxide and chlorofluorocarbons by the natural as well as human activities is the main driver causing climate change. According to recent statement given by the World Meteorological Organization (WMO), the current levels of these greenhouse gases are at unprecentded levels. In 2016, the global GHG concentrations reached new hights with CO_2 at 403.3±0.1 parts per million (ppm), CH_4 at 1853±2 parts per billion (ppb) and N_2O at 328.9±0.1 ppb. These values constitute, respectively, 145%, 257% and 122% of pre-industrial (before 1750) levels (WMO, 2018) [50]. Since 1900, the global average temperature has risen by 0.7 °C due to greenhouse gases; meanwhile, the global average temperature will increase 1-4.5 °C in the next 100 years (IPCC, 2014) [20]. The factors most likely to impact the resilience and adaptability of ecological systems are: (i) rising surface temperature; (ii) increased atmospheric CO_2 concentration; (iii) variability in precipitation; and (iv) the interactions among these factors. All of these aspects of climate have changed significantly across the globe and are projected to continue changing (Walsh *et al*., 2014) [46]. The increase in greenhouse gases have resulted in a number of noticeable climatic changes such as elevated temperatures, increased occurrence and severity of extreme weather events such as droughts, floods and intense tropical cyclones. The most expensive hurricanes like, Harvey, Irma and Maria of the United States, Floods in South Asian countries and recurring drought in horn of Africa are perfect examples of climate change which affected millions of people (WMO, 2018) [50]. The IPCC AR5 has clearly pointed out that climate change will have a strong influence on agriculture, and it could be more significant on developing countries like India, where more than 50% of population is depended on agriculture. The change in agricultural productivity patterns as a result of climate change could reduce annual agricultural incomes by between 15% and 18% on average, and between 20% and 25% particularly for non-irrigated areas (Economic Survey of India, 2018) [12]. In the changing climate scenario, understanding the incidence and dynamics of insect pests and plant pathogens is of paramount importance to formulate the effective plant protective strategies.

The majority of insects are cold-blooded invertebrates and therefore, do not use their metabolism to maintain their body temperature, but depend on surrounding temperatures for all their biological activities (Bale *et al*., 2002) [2]. Changes in the ambient temperatures may influence their life events including, the biological processes, instance development, reproduction and survival. Therefore, climate change will profoundly impact their physiology (how they live and reproduce) behaviour and physical features, as well as relationships with other species (like host plants and natural enemies). The variations in temperatures and weather patterns associated with climate change could impact insect species in different ways. For some species, these changes could have a negative impact, but for others it could be beneficial or neutral effect depending on the insect's role in plant, animal, and human health (Sharma, 2010; War *et al*., 2016) [38, 48].

Climate change will have both direct as well as indirect effects on insect pest populations. Directs effects are due to changes in population growth rates, overwintering success, migration behaviour, habitat expansion. Indirect effects arise due to trophic interactions with their host plants and natural enemies. Monitoring of insects, the climate sensitive arthropods, may serve as good indicators of climate change and enable scientists to understand the changes in biodiversity (Gregory *et al.,* 2009) [16].

Directs effects of Climate change on insect pests

1. Effect on population growth rate

Depending on the development strategy of an insect species, temperature can exert different effects. Species with high thermal tolerance will perform better during severe and frequent extreme temperature events than other species (Burgi and Mills, 2010) [5]. Increasing temperature within certain favourable ranges accelerate the rates of development, reproduction and survival in tropical and subtropical insects. Thereupon, insects will be capable of completing more number of generations per year and ultimately it will result in more crop damage (Bale *et al.,* 2002) [2]. In recent times, it was clearly observed in case of pests like Aphids and plant hoppers. It has been estimated that with a 2 ºC temperature increase, insects might experience one to five additional life cycles per season (Pandi *et al.,* 2018) [32]. In addition to sucking pests, elevated temperature benefits the some lepidopterans in many ways by increasing their flight, thus leading to higher mating success and egg laying and ultimately larger brood development. Elevated CO_2 and temperature will increase activities of enzymes (e.g. midgut proteases, carbohydrases, and mitochondrial enzymes) and metabolic rates which in turn may lead to rapid generation turnover of insect pests (Akbar *et al.,* 2016) [1]. Shrestha (2019) [39] reported that each additional degree of temperature rise could cause yield losses from insect pests to increase by a further 10-25%.

2. Effect on migrating behaviour and habitat ranges

Global warming is expected to force species to shift their distributions by expanding into the new climatic areas and by disappearing from areas that have become climatically unsuitable (Hughes *et al.,* 2003) [19]. Increasing temperatures will allow insect pests to move from tropics and subtropics to temperate regions at higher altitudes along with shifts in cultivation areas of their host plant. It is predicted that 1ºC rise in temperature would extend distribution of species 200 km northwards or 140 km upwards in altitude (Parry and Carter, 1989) [32]. This is clearly indicating that global warming will cause more crop yield losses in temperate countries due to the expansion of insect range. At the same time, it makes them as vulnerable places for introduction of new invasive pests having potential threats to their agro ecosystems. Pests that extend their range beyond those of their principal natural enemies potentially escape biological control and may cause outbreaks. In near future, it is unfortunate to note that because of short life cycle and increased fighting ability of sucking insects, viral diseases may become prevalent and cause severe crop losses to farmers (Sharma *et al.,* 2010) [38]. Several modelling studies predicted the range expansion of forest as well as agricultural insect pests. Few examples are given below. Global warming resultant altitudes wise range expansion and increased overwintering survival of corn earworms *Heliothis zea* (Boddie) and *Helicoverpa armigera* (Hubner) may cause heavy yield loss and put forth major challenge for pest management in maize (Diffenbaugh *et al.,* 2008) [10]. Warming will allow the cold intolerant pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae), to expand its range on cotton into formerly inhospitable areas affected by heavy frosts, and damage rates will increase through-out its current range (Gutierrez *et al.,* 2006) [17]. The northward expansion of the southern pine beetle, *Dendroctonus frontalis*, has been linked to improved conditions for overwintering beetles, either larvae or adults (Williams and Liebhold, 2002) [49].

3. Effect on overwintering or resting periods

Insects undergoing a winter diapause are likely to experience the most significant changes in their thermal environment (Bale and Hayward, 2010) [3]. Accelerated metabolic rates at higher temperatures shorten the duration of insect diapause due to faster depletion of stored nutrient resources. Warming in winter may cause delay in onset and early summer may lead to faster termination of diapause in insects, which can then resume their active growth and development. Lower winter mortality of insects due to warmer winter temperatures could be important in increasing insect populations (Hahn and Denlinger, 2007) [18]. A warm, dry winter will aid aphid survival and increase population in wheat. The pupae of *Helocoverpa armigera* could emerge up to 7 days earlier from winter diapause when temperatures increase (Ouyanga *et al.,* 2016) [31].

4. Effect on abundance and biodiversity

The relative abundance of different insect species may change rapidly due to climate change, and the species unable to withstand the stresses may be lost in the near future (Jump and Penuelas, 2005) [21]. As temperature increases, the species present in mountains or high latitudes are likely to be affected more and they will be forced to shift from their native range to further higher altitudes. But, even if they are able to move, they will eventually run out of habitable areas and may inevitably go extinct. In addition to temperature, large-scale changes in rainfall will have a major effect on the abundance and of diversity of arthropods. More intense rainfall may reduce the incidence of sucking pests like thrips, aphids, leaf hoppers and whiteflies. Abberent weather events causes the outbreak of insects pests for example, heavy and frequent rains may lead to the outbreak of red hairy caterpillar and long dry spells followed by intense rainfall causes the outbreak of pests like cutworms (Sardana and Bhat, 2016) [37].

Indirect effects of climate change on insects through host plants

1. Effect on host plant and insect pest synchrony

Normally, the natural timing of the insect lifecycle synchronizes with the lifecycle of the plants on which they feed. However, climate change has caused mostly negative consequences from the increasing asynchrony in ecological systems, due to variation in the phenological responses of insects and their host plants (Visser and Holleman, 2001) [45]. Many insect species feeding on specific plants will face pressure to adapt as the plants on which they feed undergo changes in their growth cycle. Therefore, expected response in insects could include an advance in timing of larval and adult emergence and increase in length of flight period (Menendez, 2007) [29]. Phenological asynchrony of winter moth (*Operophtera brumata*, Lepidoptera: Geometridae) with its wood host Oak tree, *Quercus robur* where moth eggs gamble with their own lives by hatching early (Van-Asch and Visser, 2007) [43]. It was found that 23 of 30 egg-masses laid by the bay checkerspot butterfly *Euphydryas editha* (Lepidoptera: Nymphalidae) hatched after the host plants (*Plantago* and *Castilleja*) had gone through senescence, resulting in no larvae from these clutches reaching the third instar (Singer and parmesan, 2010) [40].

2. Effect of increased Co$_2$ on host plants

Increased atmospheric CO_2 associated with global warming could stimulate plant growth because of increased photosynthesis rate of most of C_3 plants, thus increasing the amount of food available which scientist initially thought that increasing CO_2 would be a solution for world's food supply (Lamarche *et al*., 1984) [26]. Unfortunately, these optimistic predictions have not proven accurate. One reason for this is that insects also eat more when plants are grown under elevated levels of CO_2 due to poor nutritional quality of host plant. Based on the "Nutrition compensation hypothesis," elevated CO_2 can affect indirectly the development fitness of herbivores by changing the nutritional components of host plant. It had negative effects on insects by diluting the nitrogen in leaf tissues by 15-25% and increases the C: N ratio due to accumulation of non-structural carbohydrates (Lincolin *et al.*, 1993) [27]. Insects especially chewing insects such as lepidopterans have been shown to respond this ratio by accelerating their feeding in order to fulfil their metabolic needs for nitrogen to derive more amino acids called "compensatory feeding". However, phloem and xylem feeding insects such as the hemipterans may be less affected by elevated CO_2 levels (Petzoldt and Seamann, 2010) [34].

After investigating the effects of elevated CO_2 on many lepidopteran pests, several studies revealed that it prolonged larval and pupal duration and decreased pupation rate and pupal weight. It also resulted in increased relative consumption rate, decreased efficiency of conversion of ingested as well as digested food and low relative growth rate. It has been indicated that elevated CO_2 increased 19% phenols, 22% condensed tannins and 27% flavonoids, while the terpenoids and nitrogen based secondary metabolites decreased by 13% and 16%, respectively (Robinson *et.al*., 2012) [36]. Under elevated CO_2 (> 550 ppm) Increased digestibility, and decreased efficiency of conversion of ingested food into body matter have been recorded in four successive generations of caster semilooper, *Archaea janata* (L.) under elevated CO_2 (Srinivasa Rao *et al*., 2013) [41]. Higher activity of digestive and mitochondrial enzymes thereby increased rate of consumption of *Helicoverpa armigera* was observed by Akbar *et al*. (2016) [1]. Elevated CO_2 had increased the populations of brown plant hopper, *Nilaparvata lugens* (Prasannakumar *et al*., 2012) [35] wheat aphid, *Sitobion avenae* (Chen *et al*., 2004) [7] and potato aphid, *Macrosiphum euphorbiae* (Sudderth *et al*., 2005) [42].

Effect of increased temperature on host plants

Elevated temperature accelerated the photosynthesis in host plants, which would contribute towards enhancing their nutritional quality. It has shown to enhance the herbivory of insects indirectly by changing the growth potential of host plants, leading to the outbreak of pests (Visser and Both, 2005) [44]. In addition to that the production of plant secondary metabolites and other plant defensive traits will be affected and may become vulnerable to insect attack. Further, some studies have shown adverse effects of elevated temperature on herbivores, including altered developmental period and expansion of the use of plant resources for other herbivores. Zhang *et al.* (2018) [51] observed the significant decrease in the larval duration, pupal duration and pupal weight of *S. litura* larvae fed on soybean grown in elevated temperature in contrast to ambient temperature. Early onset of infestation by *H. armigera* in cotton and pulses in Northern India may be due to reduced host defenses as a result of temperature stress (Sharma, 2010) [38].

4. Combined effect of elevated CO_2 and temperature on insect pests

Under the condition of simultaneous occurrence of elevated CO_2 and global temperature rise, the combination of temperature and CO_2 concentration will have a series of complex influences on the growth and population dynamics of agricultural insects. In a meta-analytical review of 42 studies that simultaneously increased carbon dioxide and temperature conditions compared with ambient conditions, Zvereva and Kozlov, (2006) [52] showed that nitrogen concentration in plants was reduced under both elevated CO_2 and elevated temperature conditions, and this decrease was stronger for woody compared with herbaceous plants. A ratio of C/N in plants was increased under elevated CO_2 and temperature treatments, but carbon-based secondary compounds did not show a significant response to increases in either CO_2 or temperature. It also reported that herbivore performance in terms of survival, pupal weight, relative growth rate and fecundity, was negatively affected by elevated CO_2 alone, but positively affected by elevated temperature; when acting simultaneously, these two factors had no detectable effects on insect performance (Cornelissen, 2011) [8]. However, recent studies observed detectable variation in insect population due to the interactive effect of elevated CO_2 and temperature. Pandi *et al*. (2018) [32] observed that elevated CO_2 and temperature had exhibited positive effect on BPH multiplication, enhancing its population (55.2 ± 5.7hoppers/hill) in comparison to ambient CO_2 and temperature (25.5 ± 2.1 hoppers/hill). In a China based study, Zhang *et al.* (2017) observed the decrease in relative growth rate (RGR), Efficiency conversion of ingested food (ECI) Efficiency conversion of digested food and increase of the actual daily when *S. litura* fed on a soybean cultivar.

5. Effect on host plant distribution

Climate change can also influence the geological distribution of plant species and their growth patterns. There will be changes in the abundance and distribution of its cultivated and uncultivated host plants would the insect pest distribution. New pests may arise, while some pests may become invasive by reaching new areas due to extended range of their host plants. Wang *et al.* (2016) in their modeling study on global distribution of Colorado potato beetle revealed the risk of invasion of the beetle from its native range includes most of southern and central North America (Mexico and United states) to non-native areas including northern, central and southern Africa and Asia, including Madagascar, Asia Minor, Pakistan, India, Bangladesh, Nepal, much of eastern China and large areas in Australia.

Climate change indirectly can also influence biological distribution of vector borne diseases and diseases caused by parasite will rise. In some part of the world, there will be increased disease outbreak and some part may witness reduced outbreak of diseases too based on the type of disease parasite or vector available at a given time and space (Nwaerema, 2020) [30].

Indirect effect of climate change on insects through natural enemies

The understanding of the response of insect pests and their natural enemies to climate change is very important for effective biological control of insect pests. The effect of climate change on natural enemies is highly complex. Relationships between pests and their natural enemies will change as a result of global warming; resulting in both increases and/or decrease in the status of individual pest species.

1. Effect on biology of the natural enemies

Successful biological control of insect pests mainly depends on the viability of natural enemy populations and the per capita ability of these natural enemies to locate attack and process prey. Climate change will directly affect the physiology and behaviour of natural enemy and prey, altering the effectiveness of biological control. Warming will have the greatest direct effect on predator and prey biology, ranges and phonologies, whereas increasing CO_2 could have indirect effect by altering the chemistry of host plants, while rainfall may have varied effects due to their uncertain pattern. Generally, the highest prey attack and intake rates were near 24 °C and 26 °C, respectively, suggesting sustained average temperatures above these values might begin to impair the biological control. It has been reported that higher CO_2 could make generalist predators or parasites more effective in controlling pests than the specialists (Eigenbrode *et al.*, 2015) [13].

Dyer *et al*. (2013) [11] observed the low parasitism and risk of extension of armyworm parasites because of short developmental period of its caterpillars while feeding on lucerne under elevated CO_2 and temperature conditions. Klaiber *et al*. (2013) [24] reported that elevated CO_2 had reduced the population of *Diaeretiella rapae*, a specialized parasitoid of an aphid host by about 50 percent. The parasitic wasp, *Cotesia marginiventris* Cresson (Hymenoptera: Braconidae), failed to complete development in its host, *Spodoptera exigua* Hubner (Lepidoptera: Noctuidae) at 33 °C, but developed successfully at 26 °C, suggesting that warming could interfere with biological control (Butler and Trumble, 2010).

2. Effect on insect pest-natural enemy synchrony

Temporal co-occurrence of the vulnerable stages of the pest and the attacking stage of the natural enemy is very critical for the success of biological control especially the classical biological and conservation biological control programmes which depends on adequate synchrony of target pest and natural enemies With the changing climate scenario, temporal asynchronies between interacting populations even they may lead to death of the natural enemies (Karuppaiah and Sujayanad, 2012) [23]. Many studies regarding poor synchrony between a parasitoid and its host have been documented. Evans *et al.* (2012) [14] based on their 10 years data observed the asynchrony between the cereal leaf beetle, *Oulema melanopus* L. (Coleoptera: Chrysomelidae) and the introduced specialist parasitoid wasp, *Tetrastichus julis* Walker (Hymenoptera: Eulophidae), during warmer springs in Cache Valley, Utah.

3. Effect on interspecific interactions of natural enemies

If temperatures increase, the development times of the two natural enemy species change differentially and alter the abundance of natural enemies in ecosystem. Natural enemy species that are capable of long-distance dispersal may expand their ranges more rapidly and play a larger role in biological control than species with limited dispersal capabilities. We can also expect that specialist natural enemies such as many parasitoids are likely to be influenced disproportionately by climate change compared to generalists, due to a high degree of dependence on a single host (Gilman *et al.*, 2010) [15]. Warming may affect the volatiles produced by the host plant thereby alter the searching behaviour and feeding rate of natural enemy communities (Bruce *et al.*, 2011) [4].

Impact of climate change on pest management

Some of the components of pest management strategies such as host plant resistance, natural enemies, bio-pesticides, and synthetic chemicals will be rendered less effective as a result of increase in temperatures and UV radiation, and decrease in relative humidity. Since climate change will lead to a shift in cultivation of crops in non-traditional areas and crop rotations. However, changes in cropping patterns as a result of climate change will drastically affect the balance between insect pests and their natural enemies (Maiorano *et al.*, 2013) [28]. Some cultural practices like crop rotation, early or late planting etc. will be less or no effective with changing climate because of shrinking of crop growing seasons, colonization of crops by early insect arrival and or increased winter survival. Asynchrony between insect-pests and their natural enemies may upset the natural balance of biological control. Pesticides like pyrethroids, organophosphates and bio pesticides being highly thermo-unstable degrade faster at higher temperatures. Altered temperature regimes may render many of these products to be less or no effective in pest control, necessitating frequent insecticide applications for effective control. This may intensify the pest problems due to the increased chances of development resistance insects, pest resurgence and secondary pest outbreaks. Ultimately it will increase production cost to the farmers (Petzoldt and Seaman, 2010) [34].

Conclusion

Climate change threatens global food supplies by improving breeding grounds for some pests, allowing others to damage vulnerable plants and pushing invasive pests into areas that are unequipped for them. These having serious consequences on diversity and abundance of arthropods and the extent of losses due to insect pests, which will impact crop production, plant protection and food security. Effect of climate change is more in temperate insects affect the range expansion, host and enemy synchrony and interspecific competition. Among the various abiotic factors, temperature is very important because of poikilothermic nature of insects. Hence the possible effects of climate change on insect pests could result in their outbreaks, migration, dispersion, change in biodiversity, species extinction, change in host, survival, growth and development, voltinism, longevity, parasitism, dispersal of natural enemies and increased number of generations and emergence of new resistant biotypes. The CO_2 cause indirect effect through host nutrient alteration and having both positive and negative effects. Adverse effects of climate change on the activity and effectiveness of natural enemies will be a major concern in near future pest management programs. Climate change is one of the problems caused by human activities and can also be minimized by human activities. Therefore, there is a need to have a concerted look at the likely effects of climate change on crop protection, short term and long term conservation on bio-control agent mainly natural enemies which need greater attention to understand and address those issues through further research.

References

1. Akbar SM, Pavani T, Nagaraja T, Sharma HC. Influence of CO_2 and temperature on metabolism and development of *Helicoverpa armigera* (Noctuidae: Lepidoptera). Environment Entomology. 2016; 45:229-236.
2. Bale J, Masters GJ, Hodkins ID, Awmack C, Bezemer TM, Brown VK, *et al*. Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Global Change in Biology. 2002; 8:1-16.
3. Bale JS, Hayward SAL. Insect overwintering in a changing climate. Journal of Experimental Biology. 2010; 213:980-994.
4. Bruce TJA, Picket JA. Perception of volatile blends by herbivorous insects-Finding the right mix. Phytochemistry. 2011; 72:1605-1611.
5. Burgi LP, Mills NJ. Cold tolerance of the overwintering larval instars of light brown apple moth *Epiphyas postvittana*. Journal of Insect Physiology. 2010; 56:1645-1650.
6. Butler CD, Trumble JT. Predicting population dynamics of the parasitoid *Cotesia marginiventris* (Hymenoptera: Braconidae) resulting from novel interactions of temperature and selenium. Biological Science and Technology. 2010; 20:391-406.
7. Chen FJ, Wu G, Ge F. Impacts of elevated CO2 on the population abundance and reproductive activity of aphid *Sitobion avenae* Fabricius feeding on spring wheat. Journal of Applied Entomology. 2004; 128:723-730.
8. Cornelissen T. Climate change and its effects on terrestrial insects and herbivory patterns. Neotropical Entomology. 2011; 40:155-163.
9. Coviella CE, Stipanovic RD, Trumble JT. Plant allocation to defensive compounds: interactions between elevated CO2 and nitrogen in transgenic cotton plants. Journal of Experiment Botany. 2002; 53:323-331.
10. Diffenbaugh NS, Krupke CH, White MA, Alexander CE. Global warming presents new challenges for maize pest management. Environment Research Letter. 2008; 3:1-9.
11. Dyer L, Richards L, Short S, Dodso C. Effects of CO_2 and temperature on tritrophic interactions. PLoS One. 2013; 8:25-28.
12. Economic Survey of India. Climate, Climate Change, and Agriculture. Vol I, Chapter 6, Ministry of finance, Government of India, 2018, 88-101.
13. Eigenbrode SD, Davis TS, Crowder DW, Bjorkman C, Niemela P. Climate change and biological control in agricultural systems: principles and examples from North America In: Bjorkman C, Niemela P (eds) Climate change and insect pests, 2015, 119-135.
14. Evans EW, Carlile NR, Innes MB, Pitigala N. Warm springs reduces parasitism of the cereal leaf beetle through phonological mismatch. Journal of Applied Entomology. 2012; 137:321-400.
15. Gilman S, Urban M, Tewksbury J, Gilchrist G, Holt R. A framework for community interactions under climate change. Trends in Ecology Evolution. 2010; 25:325-331.
16. Gregory PJ, Johnson SN, Newton AC, Ingram JS. Integrating pests and pathogens into the climate change/food security debate. Journal of Experiment Botany. 2009; 60:2827-2838.
17. Gutierrez AP, D' Oultremont T, Ellis CK, Ponti L. Climatic limits of pink bollworm in Arizona and California: effects of climate warming. Acta Oecologica. 2006; 30:353-364.
18. Hahn DA, Denlinger DL. Meeting the energetic demands of insect diapause: nutrient storage and utilization. Journal of Insect Physiolog. 2007; 53:760-773.
19. Hughes CL, Hill JK, Dytham C. Evolutionary trade-offs between reproduction and dispersal in populations in expanding range boundaries. Proceedings of the Royal Society of London. Series B: Biological Sciences. 2003; 270(2):147-150.
20. IPCC. Impacts, adaptation and vulnerability. Working group II contribution to the fifth assessment report of the intergovernmental panel on climate change In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (Eds.).Cambridge University Press, Cambridge, UK, 2014, 1132.
21. Jump AS, Penuelas J. Running to stand still: adaptation and the response of plants to rapid climate change. Ecology Letter. 2005; 8:1010-1020.
22. Kang Y, Khan S, Ma X. Climate change impacts on crop yield, crop water productivity and food security - A Review. Progress in Natural Science. 2009; 19:1665-1674.
23. Karuppaiah V, Sujayanad GK. Impact of Climate Change on Population Dynamics of Insect Pests. World Journal of Agricultural Science. 2012; 8:240-246.
24. Klaiber J, Najar-Rodriguez AJ, Dialer E, Dorn S. Elevated carbon dioxide impairs the performance of a specialized parasitoid of an aphid host feeding on *Brassica* plants. Biological Control. 2013; 66:49-55.
25. Kranthi KR, Naidu S, Dhawad CS, Tatwawadi A, Mate K, Patil E, *et al*. Temporal and intra-plant variability of Cry1Ac expression in Bt-cotton and its influence on the survival of the cotton bollworm, *Helicoverpa armigera* (Hubner) (Noctuidae: Lepidoptera). Current Science. 2005; 89:291-298.
26. LaMarche VC, Graybill DA, Fritts HC, Rose MR. Increasing atmospheric carbon dioxide: tree ring evidence for growth enhancement in natural vegetation. Science. 1984; 7:1019-1021.
27. Lincoln DE, Fajer ED, Johnson RH. Plant-insect herbivore interactions in elevated CO2 environments. Trends in Ecology and Evolution. 1993; 8(2):64-68.
28. Maiorano L, Amori G, Capula M, Falcucci A, Masi M, Montemaggiori A, *et al*. Threats from Climate Change to Terrestrial Vertebrate Hotspots in Europe. PLoS ONE. 2013; 8(9):749-759.
29. Menendez R. How are insects responding to global warming? Tijdschrift voor Entomologie. 2007; 150(2):355-365.

30. Nwaerema P. Impact of Climate Change on Insects, Pest, Diseases and Animal Biodiversity. International Journal of Environmental Science and Natural Resource. 2020; 23(5):151-153.
31. Ouyang F, Hui C, Men X, Zhang Y, Fan L, Shi P, *et al*. Early eclosion of overwintering cotton bollworm moths from warming temperatures accentuates yield loss in wheat. Agriculture Ecosystem and Environment. 2016; 217:89-98.
32. Pandi GG, Chander S, Singh MP, Pathak H. Impact of elevated CO_2 and temperature on brown planthopper population in Rice ecosystem. National Academy of Science, India Section B: Biological Science. 2018; 88:57-64.
33. Parry ML, Carter TR. An assessment of the effects of climatic change on agriculture. Climatic Change. 1989; 15(2):95-116.
34. Petzoldt C, Seaman A. Climate Change Effects on Insects and Pathogens. Climate Change and Agriculture: Promoting Practical and Profitable Responses, New York State Agricultural Extension Station, Geneva, NY 14456, 2010, 01-27.
35. Prasannakumar N, Chander S, Pal M. Assessment of impact of climate change with reference to elevated CO_2 on rice brown planthopper, *Nilaparvata lugens* (Stal.) and crop yield. Current Science. 2012; 103:1201-1205.
36. Robinson EA, Ryan GD, Newman JA. A meta-analytical review of the effects of elevated CO_2 on plant–arthropod interactions highlights the importance of interacting environmental and biological variables. New Phytology. 2012; 194:321-36.
37. Sardana HR, Bhat MN. Pest Scenario, Plant Protection Approaches in the Current Context of Changing Climate. In: Chattopadhyay C, Prasad D (eds), Dynamics of crop protection and climate change, Studera press, New Delhi, 2016, 167-186.
38. Sharma HC. Global warming and climate change: Impact on arthropod biodiversity, pest management, and food security. In: Perspectives and Challenges of Integrated Pest Management for Sustainable Agriculture, Thakur R, Gupta PR, Verma AK (Eds.) Souven Natn Symp Nauni, Solan, Himachal Pradesh, 2010, 1-14.
39. Shrestha S. Effects of Climate Change in Agricultural Insect Pest. Acta Scientific Agriculture, 2019, 74-80.
40. Singer MC, Parmesan C. Phenological asynchrony between herbivorous insects and their hosts: signal of climate change or pre-existing adaptive strategy? Philosophical Transactions of the Royal Society B: Biological Sciences. 2010; 365:3161-3176.
41. Srinivasa Rao M, Srinivas K, Vanaja M, Manimanjari D, Rao CAR, Venkateswarlu B, *et al*. Response of multiple generations of semilooper, *Achaea janata* feeding on castor to elevated CO_2. Journal of Environmental Biology. 2013; 34:877-883.
42. Sudderth EA, Stinson KA, Bazzaz FA. Host-specific aphid population responses to elevated CO2 and increased N availability. Global Change Biology. 2005; 11:1997-2008.
43. Van Asch M, Visser ME. Phenology of forest caterpillars and their host trees: the importance of synchrony. Annual Review of Entomology. 2007; 52:37-55.
44. Visser ME, Both C. Shifts in phenology due to global climate change: the need for a yardstick. Proceedings of the Royal Society of London. Series B: Biological Sciences. 2005; 272:2561-69.
45. Vissers ME, Holleman LJM. Warmer springs disrupt the synchrony of oak and winter moth phenology. Proceedings of the Royal Society of London. Series B: Biological Sciences. 2001; 268:289-294.
46. Walsh J, Wuebbles D, Hayhoe K, Kossin J, Kunkel K. Our Changing Climate- Climate Change Impacts in the United States. In: Melillo JM, Richmond TTC, Yohe GW (Eds), the Third National Climate Assessment. US Global Change Research Program, Washington DC, 2014, 19-67.
47. Wang C, Hawthorne D, Qin Y, Pan X, Li Z, Zhu S, *et al*. Impact of climate and host availability on future distribution of Colorado potato beetle. Science Rep. 2017; 7:4489.
48. War AR, Taggar GK, War MY, Hussain B. Impact of climate change on insect pests, plant chemical ecology, tritrophic interactions and food production. International Journal of Biological Science. 2016; 1:16-29.
49. Williams DW, Liebhold AM. Climate change and the outbreak ranges of two North American bark beetles. Agriculture for Entomology. 2002; 4:87-99.
50. WMO. WMO Statement on the state of the Global Climate in 2017. Communication and Public Affairs Office, World Meteorological Organization, Geneva 2, Switzerland, 2018, 9.
51. Zhang YF, Wan GJ, Liu B, Zhang XG, Xing GN, Chen FJ, *et al*. Elevated CO_2 and temperature alter development and food utilization of *Spodoptera litura* fed on resistant soybean. Journal of Applied Entomology. 2018; 42:250-62.
52. Zvereva EL, Kozlov MV. Consequences of simultaneous elevation of carbon dioxide and temperature for plant-herbivore interactions: A meta-analysis. Global Change Biology. 2006; 12:27-41.