

Impact of global warming on the insect pest status on plants

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Abstract

Green house gases capture the heat radiation from the sun and maintain an average global temperature of 15°C in the lower most atmospheric layer, the troposphere, which supports the life of our planet. Increase in the concentrations of green house gases in the atmosphere due to anthropogenic, animal and microbial activities, creates an “enhanced global green house effect” in the recent time, causing “Global Warming”. This phenomenon affects various climatic and natural processes that also include adverse changes in the insect pest status on the agricultural, horticultural and forest plants. Under the elevated ambient temperature and concentrations of green house gases like CO₂, the pest species exhibit increased herbivory, longevity, voltinism, reproductive cycles, fecundity, population size, and pesticide resistance. The plant's natural phytochemical defense mechanism against insect attack also decreases under raised green house effect. This induces over damage to plants by enhancing the longevity and fecundity and population of the pest species. Plants also shift their other chemical defense mechanisms from nitrogen-based chemicals to carbon-based chemicals under high CO₂ environment. The high level of carbohydrate in relation to nitrogen in plants produced under elevated ambient CO₂ amount also accounts for over herbivory by the insects to satisfy their nitrogen requirement. Hence, increased pest status of insects, besides necessitating costlier control measures, definitely inflicts an irreversible damage to the plant lives of our planet.

Keywords: Green houses gases, voltinism, phenology, herbivory, longevity, fecundity, deterrent & signaling phytochemicals.

Introduction

Global warming [GW] is the inevitable result of the enhanced green house effect that is caused due to the increased levels of green house gasses [GHG] like Carbon-dioxide [CO₂], Chlorofluorocarbon [CFC], Methane [CH₄] and Nitrous oxide [N₂O] in the atmosphere. According to the report of the Working Group of the Intergovernmental Panel on Climate Change (IPCC, 2001) the average global surface temperature had increased by 0.6 ± 0.2°C over the last century and is estimated to still increase 1.4-5.8°C above the present normal level by 2100, if the input of GHG continues to rise at the present rate. Among all other factors like man, animals and microbes, the anthropogenic [man-made] actives contribute the major share in the enhancing levels of atmospheric GHG. It is estimated that around 60% of global warming, due to human activity, is contributed by CO₂ emission (WNA publication, 2008) and is mainly produced from burning of fossil fuel and cleared materials from land and deforestation. The more accumulating green house gases in the air absorb and reradiate the thermal infrared energy to earth surface that causes the increase of mean global ambient temperature even beyond the normal level of 15°C. The global warming with increased level of CO₂ is certainly known to bring about quality and quantity changes in the agricultural, horticultural and forest plants that will alter the incidence, abundance and distribution pattern of insect pest species (Sionit, 1983; Scriber and Slansky, 1981; Kiritani, 2006). The impact of climate change with

elevated GHG levels on the insect pest status with reference to their longevity, winter mortality, fecundity, population out breaks, insecticide resistance and plant defense mechanisms against insect herbivory are reviewed in the present paper.

Development & Voltinism:

As the insects are poikilotherms, their growth and development are influenced by changes in the ambient temperature. Fielding and Defoliart (2010) reported in grasshoppers *Melanoplus borealis* and *Melanoplus sanguinipes*, 2-4°C increase of soil temperature shortened the embryonic development and diapausing period of over wintering eggs and advanced the egg hatching by 3-7 days, that resulted in the population increase in warmer years. Temperature rise can also increase the rate of postembryonic larval development and accounts for early emergence of adults with a subsequent extended period of flight activity. Roy and Sparks (2000) reported a flight period advancement in butterflies by 2-10 days for every 1°C rise in temperature. Earlier appearances of butterflies by 1-7 weeks per 15 years in Spain (Stefanescu *et al.*, 2003) and 8 days per 10 years in California (Forister and Shapiro, 2003) due to climatic temperature increase have been reported. Aphids, another potential pest groups, are also known to have earlier appearance and arrival at United Kingdom (Zhou *et al.*, 1995) under more warming condition.

Number of generations per unit time, voltinism, has a definite bearing on the insect population size and increase. Climatic warming is understood to trigger



around 44 species of European Butterflies to increase their voltinism after 1980 (Altermatt, 2010). Similar such increase in voltinism of other potential pests due to warming will account for their outbreak causing economic loss to agriculture, horticulture and forestry. Diapause during unfavorable climatic conditions like winter is a common phenomenon in insects. Increase in the surface temperature may have a profound effect on the initiation and termination of diapause with a subsequent change in the voltinism. Phonological studies by Tobin *et al.* (2008) on multivoltine grape berry moth, *Paralobesia viteana*, showed such temperature dependent changes in diapause and voltinism that are correlated with increase in mean surface temperature by 2°C. Further, a warmth-related extra generation in the grape berry moth, *Endopiza viteana*, is predicted in northeastern United States and Niagara Peninsula of Canada (Tobin *et al.*, 2003). Observations on the phenology of some important coleopteran, lepidopteran and hemipteran pests of rice in Japan showed an increased voltinism as the climatic temperature exceeds the mean ambient level of 15°C by 2°C in 1998. In higher latitudes and altitudes where the global warming is predicted to be higher (Houghton *et al.*, 2001) the phonological changes of insect in relation to temperature rise would be imminent to aggravate their pest status.

Herbivory, longevity & fecundity:

Industrial revolution resulted in a vast increase in the atmospheric CO₂ level from 280 to 370 ppm (IPCC, 2001) and its current level is predicted to double with in next 100 years (Ehhalt *et al.*, 2001). Enhanced CO₂ level will trigger biochemical and physiological changes in the plants in relation to photosynthesis and nutrient content and that will definitely influence the extent of herbivory, longevity and fecundity of insect pests. Although a slower growth rate with increased larval mortality and lower fecundity is reported in some lepidopteran insects like *Helicoverpa armigera* (Wu *et al.*, 2006), the life span of Japanese beetle, *Popillia japonica*, a major pest of Soybean (*Glycine max*), is prolonged by 8.25% when fed on foliages developed under elevated CO₂. Besides, females fed on such foliages laid approximately twice as many eggs as females fed on foliages grown under normal ambient conditions (O'Neill *et al.*, 2008). A higher level of sugars like glucose, sucrose and fructose in Soybean foliages grown under higher CO₂ is considered to be a preferential factor for Japanese beetle, *P. japonica*, to feed on them. Likewise, Chen *et al.* (2004) and Xing *et al.* (2003) correlated a higher fecundity in aphids with higher carbohydrate levels in food plants grown under elevated CO₂ level. Plants can defend themselves from insect herbivory by producing phytochemicals. Casteel *et al.* (2008) showed in soybean a low level of deterrent phytochemicals under high ambient CO₂ that allows the

insects, particularly the Japanese beetle to feed voraciously on the plants.

An accelerated rate of Photosynthesis in plants is evident under high CO₂ level. This may result in the increased proportion of carbohydrate relative to nitrogen in the plant tissues and that will alter the carbon to nitrogen ratio. Under such changed carbon-nitrogen ratio the plant feeding insects are expected to eat more plant parts to meet their required nitrogen needs. Soybean plants grown in Free Air Concentration Enrichment [Soy FACE] open air lab condition with high CO₂ produced more carbohydrates and less nitrogen that attracted more Japanese Beetles, Western Corn rootworms and aphids to feed on them (Science Daily, 2008).

Fifty five million years ago rapid increase in global temperature with high CO₂ level was seen in Earth during Paleocene and Eocene epochs .of Cenozoic era. Evidences from the studies of the fossil leaves of the Paleocene-Eocene Thermal maximum [PETM] showed 50 types of extensive damages caused by insect herbivory like holes of varying sizes, chewed-out areas, galls and mines (Curran *et al.*, 2010). Likewise, the present earth warming can also be predicted to cause large-scale damage to plants through increasing the rate of insect herbivory. Climate change alters the gene nature too in insects. A known case of gene in *Drosophila*, AdhS, which encourages the survival in hot and dry weather, is observed to geographically shift to an extent of 400 km southward in Australia. This makes the flies to live longer in warmer parts of most southern parts of Australia (Hopkins, 2005).

Population size, growth, distribution and outbreak:

Kiritani (2006) reported a sequential change in the rice pest status due to climatic warming in Japan since 1945. The dominance of pyralid moths from 1945 to 1965 was successively replaced by delphacid and cicadellid homopterans in 1965-1995 and then recently by various kinds of rice bugs. Around 65 species of multivoltine and polyphagous heteropteran bugs have been known to increase their populations among which twelve of them caused major outbreaks in Japan (Tomokuni *et al.*, 1993). Population outbreaks due to enhanced fecundity under warm condition are attributed for the widening of distribution range of the pyralid rice pest, *Chilo suppressalis* in Hokkaido Island of Japan (Morimoto *et al.*, 1998; Kiritani and Morimoto, 2004). Similar outbreak of a noctuid moth, *Tricho plusiani*, on vegetables in Japan is suspected to be the after effect of global warming (Yase, 2005). As an important abiotic factor, temperature is also known to influence the population of the plant hopper, *Ricania fenestrata*, a polyphagous homopteran pest of tea plants, and its population on the plants, *Casuarina equisetifolia* and *Clerodendrum inerme*, was more under high temperature along with high humidity due to more

amount of air water vapor, another factor for air warming (Swaminathan & Ananthakrishnan 1984).

As a result of GW the tropical and subtropical insect species are observed to expand their range of occurrence northwards. Such expansion is evident in the mirid bug, *Stenotus rubrovittatus*, which had extended its range of infestation with population outbreak towards higher latitudes of Honshu and throughout Hokkaido islands in Japan (Hayashi, 1997 & Ito, 2004). Distribution of North American native spruce budworm, *Choristoneura fumiferana*, the invasive gypsy moth, *Lymantria dispar* and native mountain pine beetle, *Dendroctonus ponderosae*, are forecasted to advance towards poles and higher altitudes under climatic warming (Regniere, 2009). Logan and Powell 2001 recorded a northward range expansion of a major forest pest, mountain pine beetle, *D. ponderosae*, by 300 km with temperature increase of 3.5°F in United States and Canada. In the case of Diamondback moth, *Plutella xylostella*, the pest is known to recently colonize the Norwegian islands of Arctic Ocean, 800 km north of its earlier distribution range. This shift is suspected to be the result of mass movements of warm air towards higher latitudes (Coulson *et al.*, 2002). Likewise many temperate zone insect pests have widened their distribution towards sub-arctic regions (Regniere, 2009). The examples are pine processionary moth, *Thaumetopoea pityocampa*, in Europe (Battisti, *et al.*, 2006), winter moth, *Operophtera brumata*, and autumnal moth, *Epirrita autumnata*, in Scandinavia (Jepsen *et al.*, 2008) and Southern pine beetle, *Dendroctonus frontalis*, in North America (Tran *et al.*, 2007).

Lower winter mortality is considered as a decisive factor for most of the insect pests to increase their populations in higher latitudes and altitudes (Harrington *et al.*, 2001). In pentatomid bugs, it is shown that every 1° C ambient temperature rise would result in a decreased winter mortality of about 16.5% in *Nezara viridula* and 13.5% in *Halyomorpha halys*, paving the way for the bug population increase (Kiritani 2006). A model based study on the winter populations of the corn flea beetle, *Chaetocnema pulicaria*, a sporadic vector of Stewart's wilt disease on plants in northern US, showed an increased survival rate under warmer winters with a following population out break of this bacterial vector that caused severe wilt occurrence (Castor *et al.*, 1975). Climatic change can as well promote arrival and establishment of the exotic pests. Potato psyllid, *Bactericera cockerelli*, which was an occasional visitor to California from Mexico and southern most Texas during most of the 20th century. Increasing warming particularly during winter in California made this pest to establish in this region for the past seven years causing a substantial loss to potato, tomato and pepper plants (Liu and Trumble, 2007). Climate change is known to not only increase the population size of most of the pest

species but also boost the number of pest species. Bale *et al.*, 2002 observed in temperate climates, more insect species attack more host plants under rising temperature. As an important biological factor the natural enemies keep the insect populations under control. Because of climate variation researchers reported a change in their control influence on insect population. The intense outbreaks of lepidopteran caterpillars in mountain tropical cloud forests of Ecuadorian Andes are correlated with the reduced degree parasitic attack on them under enhanced climatic conditions (Stireman *et al.*, 2005). Petzoldt and Seaman (2007) predicted through their studies on climate impact on insect parasitism, an accelerated development with voltinism increase in cabbage and onion maggots, European corn borer and Colorado potato beetle that caused extensive damage to the host crops. According to them under higher temperature the host vulnerable life stages are passed on quickly before the emergence of parasitoids that makes the parasitism less effective with a resulting population outbreak of the crop insect pests.

Plant defense & insect resistance

Carbon-based compounds like phenolics and tannin and nitrogen-based based compounds like alkaloids, cyanogenic glycosides and glucosinolates are the two major types of defense phytochemicals employed by plants against insect attack. Since nitrogen-based chemicals act as toxins and repellants their effectiveness in plant defense is more than carbon-based chemicals, which are only digestible reducers. Under climatic warming with more CO₂, plants produce more carbon- based and less nitrogen-based chemicals and are subjected to greater damages by insect particularly in natural ecosystems where availability of nitrogen is low (Trumble & Butler, 2009). Bidart-Bouzat and Imeh-Nathaniel (2008) reported that the level of secondary defense plant chemicals like glucosinolates that are used against the insect herbivory is affected by changes in the atmospheric CO₂ concentrations.

In recent time genetically modified [transgenic] plants like Bt Cotton are developed to increase their defense strategies against insects by expressing some proteins with genes that are introduced in to their genome. A 25% reduction in the expression of such proteins is noticed in transgenic plants grown under elevated CO₂ level. This reduction not only allows the pests to cause out breaks but also facilitates them to develop resistance towards these nitrogen-based defense chemicals with a subsequent danger of resistant pest population selection (Trumble and Butler, 2009).

Cysteine proteinase inhibitor (CystPI) produced in plants interferes with the digestive functions of insect pests and brings down their feeding rate, growth and development (Fabrick *et al.*, 2002; Kim and Mullin, 2003). A reduction in the level of this deterrent



substance is noticed in soybean grown under more CO₂ level (O'Neil *et al.*, 2008) contributing to the voracious herbivory and high fecundity in *P. japonica* on this plant. Further, Jorge Zavala, Clare Casteel and coworkers (2008) showed that the genes responsible for chemical defense in plants against insects are deactivated under high CO₂ and the non-functioning of the gene for CystPI production under CO₂ stress in soybean may be responsible for the increased susceptibility of this crop towards attack of invasive crop pests. Enhanced CO₂ also reduces the levels of other deterrent phytochemicals in soybean such as 1-aminocyclopropane-1-carboxylate (ACC) synthase, lipoxygenase (LOX), allene oxide synthase (AOS), allene oxide cyclase (AOC), chalcone synthase (CHS), and polyphenol oxidase (PPO) that make the plant more vulnerable to insect herbivory (Casteel *et al.*, 2008).

Under the influence of insect feeding injury a hormonal signaling pathway is initiated in plants that results in the production of Jasmonic acid, a hormone which induces the PIN Gene to produce proteinase inhibitor substance that can bring down the development and longevity of the insects by interfering with their digestive functions. Casteel *et al.*, (2008 & 2009) observed that the production of Jasmonic acid is stopped under high CO₂ level with a subsequent loss of chemical defense against pest attack. This effect when coupled with high level of carbohydrates in plant tissues under elevated CO₂ attract more insects to cause severe damage to the crop plants. Further, Casteel and his co-workers (2009) reported that global warming could cause another deleterious effect in the form of deactivation of some genes responsible for the production of volatile substances that are used by plants to attract the natural enemies of the herbivorous insects. In corn, a required amount of volatile blends containing terpenoids and indole to attract natural enemies of insect pests is released to control their herbivory and this optimal release of volatiles is decreased under changed ambient thermal conditions (Gouinguene and Turlings, 2002). Vuorinen *et al.*, (2004) showed in cabbage the elevated CO₂ level decreased the emission of Jasmonic acid regulated terpene volatiles that reduced the searching efficiency of the parasitoid natural enemy, *Cotesia plutellae*. Hence, global warming with increased CO₂ can be expected to certainly affect the chemical-defense-signaling system in plants and that will render them more susceptible insect pest attack. The increased number of generations per year and frequent population outbreaks of potential insect pests necessitate continual applications of high amount of insecticides and that will make the insects to develop resistance against these chemicals (Petzoldt and Seaman, 2007). Further, the increased voltinism with prolongation of lifespan in insects under high CO₂ and temperature will stabilize such insecticide resistant insect varieties in the population, which will cause

greater damage to plants even under extensive insecticide control measures.

Conclusion

Although the Global warming with increased levels of Green House Gases causes a reduction in the pest performance of some insects, in many insect pest cases increased pest status are reported by many researchers. This evident particularly in notorious pests such as Japanese beetle, *Popillia japonica*, Diamond backed moth, *Plutella xylostella*, pyralid rice pest, *Chilo suppressalis*, gypsy moth, *Lymantria dispar*, corn flea beetle, *Chaetocnema pulicaria*, mountain pine beetle, *Dendroctonus ponderosae*, European corn borer, *Ostrinia nubilalis*, and Colorado potato beetle, *Leptinotarsa decemlineata*. These pests are reported to increase their herbivory, longevity, fecundity and voltinism as an indirect effect of climate change on host plants like more carbohydrate accumulation in relation to nitrogen, reduction in the level and effectiveness of deterrent chemicals against insect herbivory and signalling phytochemicals towards natural enemies for the rescue. These reasons are mainly responsible for the predicted increased pest status of insects under climate change in our globe that will create a heavy burden on the economy to implement control measures against this highly versatile group of organisms.

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