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Prospects and Challenges of Emerging Insect Pest Problems *vis-à-vis* Climate Change

Yousra Mukhtar, Uma Shankar* and Zahid Abass Wazir

Division of Entomology, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences & Technology Chatha, Jammu-180 009, India
**E-mail: shankaruipm@gmail.com*

***Abstract*:** Emerging insect pests are a constant threat to mankind and their sudden upsurge and outbreak not only affects the crop yield and biodiversity but also poses a constant threat to global trade in agriculture. According to an estimate, these pests cause diverse losses ranging from 18-20 per cent in Indian agriculture. It is evident from the literature that American bollworm, *Helicoverpa armigera*; Brown plant hopper; *Nilaparvata lugens*, Diamondback moth, *Plutella xylostella*; Pink stem borer, *Sesamia inferens*; Whitefly, *Bemisia tabaci*; Wheat aphid, *Macrosiphum miscanthi* and many more have emerged as key pests on various crops in recent years. Recent incidence of Fall Armyworm (*Spodoptera frugiperda*) on maize and other crops has also drawn attention of researchers and policy makers to issue a nation-wide advisory to the farming community to safeguard their produce as well as to combat against this dreaded pest. Various activities such as excessive usage of fertilizers, faulty cropping pattern, introduction of high yielding and hybrid varieties, indiscriminate and injudicious use of pesticides, etc. have had a tremendous impact on resurgence, resistance and secondary outbreak of insect pests. However, one of the main reasons, which has usually been neglected by us, for changing status and scenario of insect pest species is Climate aberration or in broader perspective 'Climate Change'. This article discusses the issues concerned to some emerging insect pests, their probable reasons of outbreak and providing the way out to devise timely and effective ecological based Integrated Pest Management solutions to mitigate the losses throughout our country.

***Keywords*:** Emerging insect pest, Outbreak, Invasive pest, Pesticide, Climate change

Frequent outbreaks of emerging insect pests have drawn attention of scientific community as well as policy makers to mitigate the damage inflicted to the cultivated crops and thereby, enhance the crop productivity to feed the rapidly growing population. The status of the pest changing from minor to major or from secondary to primary is labelled as an Emerging Insect Pest. Due to certain anthropogenic activities like changes in crop cultivation practices, low key crop management practices or due to natural reasons which are not in favour of a particular pest, the other insect pests find enough quantity of resources to feed on in absence of the major pest and reproduces more rapidly, thus, emerging as major or key pests.

Global losses due to pests: Since the dawn of agriculture, the constant interaction of crops with pests has been a cause of concern to farmers as they inflict considerable loss and destruction to cultivated crops, livestock, stored products, cattle feed, etc. These pests can either be insects, pathogens, weeds, virus, fungi, nematodes, protozoa, or any other plant which is not needed in a particular crop ecosystem at that specific time. Among various categories of pests, maximum crop losses are done by insects (34 per cent) followed by pathogens (31 per cent), weeds (27 per cent) and virus (8 per cent) respectively. In terms of monetary value, Indian agriculture suffers an annual loss of about US$ 36 billion (Dhaliwal et al 2015). These destructive organisms reduce the quality and quantity of crop produce, hinder the viability of cultivated plants and thus, threaten the sustainability of human beings.

Change in insect pest scenario: During the pre-green revolution era (1960's), insect pests damaged food crops to a greater extent. Among the crops, maximum losses were reported in cotton (18 per cent) followed by groundnut, pulses, rice, maize, millets, wheat and sugarcane, respectively, thus accounting to an average loss of 7.2 per cent in the food crops due to insect pests. However, in the Post-Green revolution era, the losses due to insect pests gained an upsurge and thus increasing the average loss in food crops to 23.3 per cent with almost 50 per cent damage in Cotton crop alone due to insect pests (Dhaliwal et al 2010). Certain reasons have been attributed to this changing insect pest scenario *viz*., monoculture practices (Andow 1983), excessive use of fertilizers (Butler et al 2012), use of high yielding varieties (Halder and Rai 2021), non-judicious use of pesticides (Gangwar et al 2014), absence of natural enemies (Bommarco et al 2011), favourable weather conditions (Harish et al 2015) and climate change (Peace 2020). Among all these reasons, climate change is the most indubitable reason behind gradual change in the status of pests.

Climate change and projections: Climate change is no hoax. The on and off fluctuations in day-to-day weather phenomena are vividly visible. As defined by Intergovernmental Panel on Climate Change (IPCC 2007), 'Climate Change is any change in Earth's climate over time, whether due to natural conditions or because of human activity'. The upsurge in the figure of greenhouse gases *viz*., CO_2, CH_4, N_2O, etc. leads to greenhouse effects which promotes global warming. This is the prime reason for Climate change. Temperature, carbon-dioxide and precipitation are important climate projections wherein the fluctuations drastically lead a direct impact on climate change. The constant increase in various climate projections alters the incidence of crop pests' accordingly, thus impairing the sustenance of ecosystem. For example, the average global temperature has increased by 0.6°C and is expected to reach 1.1-5.4°C by the end of next century. Similarly, the carbon-dioxide concentration has increased from 280ppm to 360 ppm and is expected to reach 655 ppm by 2070. The number of rainy days has decreased by more than 15 days following a more erratic distribution. The anthropogenic emission of greenhouse gases has upsurged over a period of forty years (1970-2010). In 2010, the greenhouse gas emission has reached to 49 ± 4.5 $GtCO_2$-eq/yr. Of this, fossil fuel combustion and industrial processes contributed about 78 percent of the total increase in greenhouse gas emissions (IPCC 2014). Various policy makers and scientists have been assembled across the globe to frame out timely strategies and policies to mitigate the deleterious effects of climate change.

Climate change-Role in emerging pest problems in India: As a reason of changing climatic conditions, the insects have become much more serious in the crop ecosystem and have developed the status of major or key pests. The insect pests that have emerged as or are likely to emerge as key or serious pests due to climate change are tabulated in Table 1.

There have been certain instances of emerging insect pest problems as reported by Sharma (2016) at ICRISAT, Hyderabad. For instance, *Helicoverpa armigera* damage in pigeon pea has prevailed following wet weather conditions in Sep-Oct; Mealy bug, *Ceroplastodes cajaninae* infestation in pigeon pea has been reported under prolonged hot and dry conditions; Beet army worm, *Spodoptera exigua* damage in chickpea has been reported to be triggered by winter rains on Oct-Nov and Pink stem borer, *Sesamia inferens* damage in sorghum has been reported to emerge due to hot and dry conditions post-rainy season.

Recent pest outbreaks in relation to climate change in India: India has witnessed several instances of insect pest outbreak in the past two decades which has caused immense loss to agriculture and horticulture sector (Table 2, Fig. 1).

Sugarcane woolly aphid: Sugarcane woolly aphid, *Ceratovacuna lanigera* Zehntner (Aphididae: Hemiptera), otherwise known as 'white sugarcane aphid' is a prime pest of the family Poaceae; however, it has been found to feed on plants of other families as well like Bixaceae, Theaceae and Combretaceae. In India, its presence has been witnessed on ten different plant species. It undergoes parthenogenetic reproduction and has an anholocyclic life cycle without any

Table 1. Insects pests that have emerged and are likely to emerge as key or serious insect pests

Insect pest	Scientific name	Crop(s)
American bollworm	*Helicoverpa armigera*	Cotton, chickpea, tomato, etc.
Beet armyworm	*Spodoptera exigua*	Chickpea in southern India
Spotted pod borer	*Maruca vitrata*	Pigeonpea, cowpea.
Diamondback moth	*Plutella xylostella*	Cabbage, cauliflower
Pink stem borer	*Sesamia inferens*	Maize, sorghum, wheat
Whitefly	*Bemisia tabaci*	Cotton, tobacco
Brown planthopper	*Nilaparvata lugens*	Rice
Green leafhopper	*Nephotettix spp.*	Rice
Serpentine leaf miner	*Liriomyza trifolii*	Cotton, tomato, several other vegetables
Fruit fly	*Bactrocera spp.*	Fruits and vegetables
Mealy bugs	*Paracoccus marginatus*	Several crops
Thrips	Several species	Groundnut, cotton, chillies
Wheat aphid	*Macrosiphum miscanthi*	Wheat, barley, oats
Pod sucking bugs	*Clavigralla* spp.	Pigeon pea

Courtesy: Sharma (2016)

sexually producing generation. This pest was first reported in India from West Bengal in 1958 as a minor pest on Sugarcane (Basu and Banerjee 1958). Afterwards, it spread to Tripura, Assam, Uttar Pradesh, Arunachal Pradesh and Sikkim till 1979 but was still considered a minor pest. This pest damages the plant by congregating on both sides of the leaves and sucking up the plant sap and as a result, the plant turns yellow, loses its vigour resulting in reduced crop yield. Under severe infestation, the plant wilts and dies off. The infested leaves develop sooty mould and as a result turn black which causes reduced photosynthesis, thus, affecting the yield of the crop (Patil 2002). In 2002, the outbreak of sugarcane woolly aphid was noticed on sugarcane in Maharashtra from where it spread to Karnataka and gained the status of a major pest (Joshi and Viraktamath 2004). Very soon, this pest damaged almost entire of the crop in these two states. By 2003-04, in Maharashtra, 2,67,000 ha area under sugarcane got infested, wherein parts of Pune and Solapur were affected the most. In Karnataka, an area of approximately 61,000 ha under sugarcane was affected during the same year wherein Belgaum and Bidar were severely affected (Sharanabasappa et al 2009). The introduction of bio-control agents viz., *Dipha aphidivora*, *Chrysoperla* spp., Coccinellids, Syrphid flies and some spiders in Maharashtra and Karnataka provided effective control over woolly aphids.

Rice plant hoppers: Brown plant hopper, *Nilaparvata lugens* Stal and White-backed plant hopper, *Sogatella furcifera* Hovarth (Delphacidae: Hemiptera) are two categories of plant hoppers that are important pests in rice ecosystem. Plant hoppers are sucking insect pests that suck the sap out of the plant, thus reducing its vitality and vigour. The most important characteristic symptom of plant hopper is 'hopper burn' which is characterized by dried, dead necrotic patches in the crop field. Its first serious epidemic occurred in 1973 over half a million-ha resulting in 10-70 per cent loss in grain yield in Indian condition. It was then succeeded by a series of Brown Plant Hopper outbreaks in Karnataka (1975 and 1985), Andhra Pradesh (1976-1983), Telangana (1980), Madhya Pradesh and Orissa (1976) and Tamil Nadu (1977 and 1982). However, in 2008-09, the epidemic form of plant hoppers occurred in Northern India and as a result, more than 3,33,000 ha rice crop failed badly (Rathee and Dalal 2018). The outbreak of plant hoppers has been attributed to several reasons viz., high humidity (>90%), high temperature (25-32°C), overuse of nitrogenous fertilizers, reduced spacing (15x10 cm), non-judicious use of pesticides, hoppers tolerance to neonicotinoids and increased mortality of natural enemies (Chander and Patel 2009). Randhawa et al (2015) reported that temperatures of 26.4-30.0℃, relative humidity between 55-99% accompanied with few showers of rain are conducive for Brown Plant Hopper population build-up. Prasannakumar et al (2012) studied the impact of elevated carbon-dioxide on brown plant hopper population on Pusa Basmati-1 during 2010-11 and opined that at an elevated carbon-dioxide concentration (570±25 ppm), the population of nymphs and adults, fecundity rate and honey dew production was three to four times more than at ambient concentration of carbon-dioxide (380±25 ppm). Similarly, Guru Pirasanna et al (2016) also studied the impact of elevated carbon dioxide and temperature on brown planthopper population in rice ecosystem in open-top

Table 2. Recent insect pest outbreak with respect to climate change in India

Insect pest	Host plants	Region/ Location	Probable reasons	Impact	Reference
Sugarcane woolly aphid, *Ceratovacuna lanigera*	Sugarcane	Maharashtra and Karnataka	Abnormal weather condition.	30% yield losses	Joshi and Viraktamath (2004)
Plant hoppers, *Nilparvata lugens; Sogatella furcifera*	Rice	North India	Abnormal weather conditions	Crop failure on >33,000 ha	IARI (2008)
Mealybug, *Phenacoccus solenopsis*	Cotton, Vegetables	Punjab, Haryana	Hot and dry weather	30-40% loss	Dhawan and Saini (2009)
Tobacco caterpillar, *Spodoptera litura*	Soybean	Maharashtra	Abnormal weather conditions	25-100% yield loss	Singh et al (2012)
Spiralling whitefly, *Aleurodicus disperses*	Tapioca	Kerala	Abnormal weather conditions	Significant yield loss	Palaniswami et al (1995)
Fall armyworm, *Spodoptera frugiperda*	Maize	Karnataka	Abnormal weather conditions	About 58% yield loss	Dhar et al (2019)
Knot grass moth, *Acronicta rumicis*	Apple	Kashmir	Abnormal weather conditions	Significant yield loss	Dar et al (2019)
Thrips, *Thrips parvispinus*	Chilli	Andhra Pradesh	Overuse of insecticides	Significant yield loss	Sireesha et al (2021)

A. Brown plant hopper infestation on paddy stem and leaves B. Hopper burn symptoms C. Infestation of *Spodoptera frugiperda* on maize D. *Phenococcus solenopsis* on Malvaceae family E. Spiralling whiteflies F. Infestation of Spiralling whiteflies on guava G. *Spodoptera litura* predation by *Eocanthecona furcellata* on soybean H. *S. litura* infestation during flowering period on soybean

Fig. 1. Emerging insect pests in India

chambers during rainy season of 2013 and found that at elevated carbon-dioxide condition (570±25 ppm+>3℃), the mean brown plant hopper population and fecundity rate of females after seven weeks of adult release was relatively more than at ambient carbon-dioxide concentration (397±25 ppm+>3℃). Use of resistant varieties like Daya, Lalat, Jyothi, Karthika, Makon, Remya, Mansarovar, etc. in hopper endemic areas, augmentation of natural enemies viz., parasitoids like *Gotnatocerus* spp. (egg parasitoid), *Pseudogonatopus* spp. (Larval parasitoid), and predators like long-jawed and orb spider and mirid bug, *Cyrtorhinus lividipennis*, crop rotation, early planting, sensible and split application of nitrogenous fertilizers can mitigate the infestation of rice plant hoppers (Prakash et al 2014).

Cotton mealy bug: The cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) is a serious polyphagous pest of approximately 21 different agricultural and horticultural crop families (Arif et al 2009). The damage is caused by both nymphs and adults by sucking up the plant sap from leaf tissues resulting into drying and wilting of plant followed by significant yield loss. They also secrete honeydew which causes sooty mould to develop leading to reduced photosynthesis (Wang et al 2009). *P. solenopsis* is an exotic insect pest species that got introduced from USA (Nagrare et al 2009). In 2006, it was reported from Pakistan and subsequently from Gujarat, followed by Punjab and Haryana (Monga et al 2009). In 2007, the infestation by two mealybug species viz., *Maconellicoccus hirsutus* and *Phenacoccus solenopsis* was reported in nine cotton-growing states of India wherein *P. solenopsis* was the predominant species (Nagrare et al 2009). Dhawan et al (2007) reported 30-40% losses in cotton yield due to mealybugs in Punjab. There has been severe economic damage to *Gossypium sp.* with 50% reduction in yields during 2006 due to infestation of mealy bug in Gujarat (Jhala 2008). In 2011 and 2014, the mealybug damage was reported on Jute in West Bengal, India (Satpathy et al 2016). The probable reasons of its outbreak on jute as reported by Gotyal et al (2014) were warm and dry conditions during seedling stage, sudden upsurge in the maximum and minimum temperature and reduced rainfall and number of rainy days from Jan-May. This pest can be effectively controlled by suitable Integrated Pest Management programmes. Proper field sanitation and removal of infested plants from field helps to reduce the pest establishment and infestation. Use of biological control agents like *Anagyrus kamali* Mani, *Cryptolaemus montrouzieri* (Mulsant), *Verticillium lecanii* (Zimmermann), *Beauveria bassiana* (Vuillemin), *Aenasius bambawalei* Hayat and *Chrysoperla carnea* (Stephens) can prove beneficial in successfully reducing the infestation by this pest on cotton (Joshi et al 2010).

Tobacco caterpillar: Tobacco caterpillar, *Spodoptera litura* Fabricus (Lepidoptera: Noctuidae) is a polyphagous pest and has emerged as a major pest of tobacco, cotton, rice, maize, soybean and groundnut over the years. This pest causes economic crop losses ranging from 25.8 to 100 per cent based on crop stage and its infestation level in the field (Natikar and Balikai 2015). There was an outbreak of tobacco caterpillar (*Spodoptera litura*) on soybean crop causing disease epidemic in Vidarbha region of Maharashtra in August 2008 (Singh et al 2012). Srinivasa Rao et al (2013) studied the impact of elevated CO_2 on tobacco caterpillar, *Spodoptera litura* on peanut, *Arachis hypogea* and reported that at 550 and 700 ppm of CO_2, the relative consumption rate and total consumption of larva was significantly more than at ambient CO_2 level. The impact of elevated CO_2 on growth parameters of *Spodoptera litura* on peanut revealed that at 500 and 700 ppm of CO_2, larval weight (g), larval duration (days) and pupal weight (g) was significantly more than at ambient concentration. Anurag et al (2020) reflected eco-friendly management of tobacco caterpillar by installing pheromone traps in the field to trap the males of *S. litura* along with spray of bio-pesticide formulation, *Bacillus thuringiensis* var. *kurstaki* for effective control of this pest.

Spiralling whitefly: The spiralling whitefly, *Aleurodicus dispersus* (Aleyrodidae; Hemiptera) is true to its name due to characteristic egg laying spiral pattern. It is a polyphagous pest that paved its way from Sri Lanka into India in 1993 on tapioca plantations of Kerala (Palaniswami et al 1995). Soon, it spread to all of the southern states of India followed by Orissa and north-eastern regions (Pradhan and Borthakur 2020). Nymphs and adults cause damage by sucking up the cell sap from the leaves, thus inflicting significant damage to different crops including cassava, chillies, mulberry, guava, banana, papaya, groundnut etc. in peninsular India (Mani and Krishnamoorthy 1999). The infestation of whiteflies depends directly on weather conditions (Mani 2010). Due to wide host range, it becomes very difficult to control this pest. Chandel et al (2010) proposed integrated Pest Management techniques to control whitefly by integrating environmental manipulation, enhancement of natural enemies and area-wide control programmes. Biological control is quite effective means of controlling whiteflies. Sugiyama et al (2011) documented three parasitoid species viz., *Eretmocerus mundus*, *E. eremicus* and *Encarsia formosa* in reducing the number of whiteflies. Very recent research has found a mite, *A. swirskii* as an effective bio-control agent of thrips and whiteflies in many crops (Messelink et al 2008). The use of yellow sticky traps is advocated to trap the adults of whitefly due to their attraction towards yellow colour (Barbedo 2014).

Fall armyworm: Fall Armyworm, *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) is the latest threat that the agriculture sector is facing. It is a polyphagous pest attacking almost every known crop family. This pest is characterized by four spots arranged in a square or trapezoid form on its eighth abdominal segment. The neonate larvae initially damage the crop by scrapping the leaf chlorophyll. The mature larvae feed on the older leaves and create window-pane like symptoms. The continuous feeding by the larvae produces moist saw dust-like frass in funnel and as a result, there is no cob formation. The outbreak of fall armyworm was first noticed in Africa in 2016 wherein 43 countries were severely affected (Dively 2018). Sisay et al (2019) surveyed various districts of Ethiopia, Tanzania and Kenya in 2017 for mean percent of fields infested by fall armyworm (FAW) along with its level of infestation in these three mentioned countries of Africa and reported that almost 100 per cent fields were infested in all the surveyed districts of the above three countries. Being highly migratory in nature, this pest rapidly spread to the nearby continents and in 2018, its outbreak was seen in Asia wherein 9 countries were severely infested including India (Dively 2018). Dhar et al (2019) reported 6 to 58 per cent yield loss in maize in India due to infestation by this pest and reported that high humidity and moderately high temperature is suitable for the spread of fall armyworm. Extreme hot areas are not suitable for the survival of this pest and it requires an optimum temperature of about 28^{o}C for spread (CABI 2019). The emergence of pest in soil is directly proportional to temperature and inversely proportional to relative humidity (CABI 2019). Firake et al (2019) suggested hand picking and egg mass destruction as an effective control measure against fall armyworm. He further demonstrated the importance of intercropping maize with leguminous crops in breaking the food chain of fall army worm. FAO (2018) reported that bio-pesticide formulations of *Bacillus thuringiensis*, *Beauveria bassiana* and Baculo viruses can effectively control this pest.

Knot grass moth: Knot grass moth, *Acronicta rumicis* Linnaeus (Noctuidae: Lepidoptera) is emerging pest of Apple plantation in Kashmir valley. This pest is widely distributed throughout the world- India (Kashmir, Himachal Pradesh), Europe, Campbellpur, Eurasia, etc. Knot grass moth larvae actively damage newly planted apple trees. They infest the terminal shoots of the developing seedling resulting in undesired apical dominance and stunted growth of the plants. In heavy infestation, heavy economic losses are inflicted. Dar et al (2019) surveyed apple plant nurseries of various districts of Kashmir from 2014-16 growing season to determine the severity of this pest in Kashmir valley. The studies indicated that out of 634 plants observed, 197 were found infested and 29 plants were severely damaged, thus revealing a total of 31.07 and 14.03 per cent incidence and severity, respectively. The computation of percentage incidence and severity contributions by each district towards the total incidence and severity in the region revealed that Ganderbal district had highest incidence and severity percentage followed by Srinagar while least incidence and severity of this pest was reported from Pulwama.

Chilli thrips: Recent outbreak of *Thrips parvispinus* (Thysanoptera: Thripidae) on chilli in south India has drawn attention of scientists and policy makers towards the emerging and invasive insect pest in posing threat to the biosecurity of Indian agriculture. In this context, Tobacco thrips, *T. parvispinus* paved its way into India in 2015 on *Carica papaya* L. plantations, wherein its invasion caused appreciable losses to the agriculture sector. Since its invasion, this pest has been reported in many fruit, ornamental and field crops. However, a recent outbreak of chilli thrips, *Thrips parvispinus* (Thripidae; Thysanoptera) has been witnessed in Andhra Pradesh which created havoc among chilli growers. Earlier, *Scirtothrips dorsalis* was the only species of thrips affecting chilli and no species of flower thrips was seen infesting this crop till 2020. However, in January 2021, several areas of Guntur district in Andhra Pradesh noticed a new species of thrips in chilli ecosystem which was later identified to be *Thrips parvispinus*. This pest primarily infests the leaves where it scraps the chlorophyll on lower leaves and sucks up the cell sap due to which the corresponding part of upper side of leaves turns yellow and the undersurface of the leaves turn reddish-brown. The leaf lamina becomes distorted and exhibits necrotic areas. Besides leaves, the floral parts are also affected by this pest where it scraps the petals causing brownish streaks on them. They may also affect pollination by feeding on the flower pollen, which affects the fruit set (Sireesha et al 2021). Scientists suggested that indiscriminate and non-judicious application of insecticides in chilli ecosystem caused this pest to resurge in epidemic form. However, it is not hidden that the changing climatic conditions favoured the survival and development of this pest and different climatic projections and their fluctuations can be attributed as a concerning reason for epidemic upsurge in *T. parvispinus.* As such, planting of pest free seedlings should be advocated. Consequently, regular monitoring and proper surveillance of this crop is required to avoid further spread of this pest to uninfested areas. Botanicals like neem oil, Pongamia oil and microbial pesticides like *Beauveria* sp. may be the potential drivers in mitigating the resurgence of this emerging insect pest and add value in sustainable cultivation of commercial chilli.

CONCLUSION

Climate change through fluctuations in climate projections *viz*., warm temperature, undistributed precipitation and increased CO_2 concentration drastically affects the insect pest population dynamics, leading to the emergence of new pests. Sucking insect pests which were earlier considered to be minor pests have now gained the status of major pests in the past two decades such as mealy bugs, plant hoppers, thrips, etc. If required measures are not taken, most pests will become ubiquitous and disperse within the places where the climate is favourable and the preferred hosts are available. Thus, there is an urgent need to modify crop production and protection measures with changing climate to tackle the problems of emerging pests in modern agriculture so as to ensure better crop protection and productivity.

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