Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2018; 7(1): 1917-1923
Received: 22-11-2017
Accepted: 24-12-2017

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Changing insect pest scenario in selected field crops-critical review

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Abstract
Crop protection always aims to avoid or prevent crop losses or to reduce them to economically acceptable level but losses due to pests had been enormously increased. Insect pest problems in agriculture have shown a considerable shift during first decade of twenty-first century due to ecosystem and technological changes. The incidences of several insect pests like mealy bugs, particularly *Phenacoccus solenopsis* on cotton; sugarcane woolly aphid, *Ceratovacuna lanigera* on sugarcane; and tobacco caterpillar, *Spodoptera litura*, on several crops, has shown an increasing trend. There was a decline in the pest status of bollworm (*Helicoverpa armigera)* whereas the sap feeders, *viz*. aphids, jassids, mirids and mealy bugs are emerging as serious pests. Recently, the occurrence of resistance in *Bt* cotton to *Helicoverpa armigera* in different regions had been reported. The global losses due to insect pests have declined from 13.6 per cent in post-green revolution era to 10.8 per cent towards the beginning of this century. In India, the crop losses have declined from 23.3 per cent in post-green revolution era to 17.5 per cent at present. In terms of monetary value, the Indian agriculture currently suffers an annual loss of about Rs 8,63,884 million due to insect pests. The climate change will also affect the pests distribution and they range from expansion in the geographical range, increased risk of invasion in new area, change in overwintering patterns, change in crop pest synchrony; change in pest complexes on spatial and temporal bases and finally pests management strategy. The impacts of climate change can be positive, negative or neutral, since these changes can decrease, increase or have no impact on insect pests and diseases, depending on specific agro climatic location of each region or period.

Keywords: caterpillar, *Spodoptera litura*, *Ceratovacuna lanigera*

Introduction

Our agriculture faces two major challenges i.e. production of sufficient food to feed the growing population, and prevention of environmental degradation. Damage by crop pests which include insects, diseases, nematodes and rodents, is one of the major constraints to increase food production. Green revolution has no doubt led to increased world food supplies, but at the same time it has caused several ecological, environmental and socioeconomic problems. Green revolution technology relied on the use of dwarf and semi dwarf high-yielding varieties of crops, increased use of agrochemicals and irrigation. All these practices favoured the build-up of crop pests, with the result that the intensity of several pests has increased, many minor pests have assumed the status of major pests and several new pest problems have appeared in certain regions. In addition, the misuse and overuse of pesticides has lead to problems of pesticide resistance, resurgence and contamination of different components of the environment. In spite of a variety of control measures applied against pests, crop losses have consistently shown an increasing trend (Dhaliwal and Koul, 2010) [13]. In addition, the climate change exerts a profound effect on the intensity of pest problems (Ramamurthy *et al.*, 2009) [59, 60].

The introduction of gene technology has added a new dimension to pest management. There are varied claims and counter-claims about the potential of gene technology in shaping the crop protection scenario in the twenty-first century (Dhaliwal, 2008; James, 2009) [17]. Therefore, reduction in losses caused by pests is the obvious strategy for increased food supply. The first systematic attempt to estimate crop losses due to various pests on global scale was made by Cramer (1967) [11]. Subsequently, extensive study to estimate losses in principal food and cash crops were investigated (Oerke, 2006) [51]. Crop losses may be caused by abiotic and biotic environmental factors, leading to the reduction of crop performance and resulting in a lower actual yield than the site-specific attainable yield of crops. Apart from these factors, there are other factors affecting the yield from producer to consumer. Hence, there is considerable shift in insect pest problems and crop losses, which form main concern to discuss in this article.

Pest Problems

Food plants of the world are damaged by more than 10,000 species of insects, 30,000 species of weeds, 100,000 diseases (caused by fungi, viruses, bacteria and other microorganisms) and 1000 species of nematodes (Hall, 1995; Dhaliwal *et al.*, 2007) [26, 21]. However, less than 10 per cent of the total identified pest species are generally considered as major pests. The severity of pest problems has been changing with the developments in agricultural technology and modifications of farming practices. The changing scenario of insect pest problems in agriculture as a consequence of green revolution technology has been well documented (Dhaliwal *et al.*, 2002; Singh *et al.*, 2002; Puri and Mote, 2003; Kumar, 2005; Dhaliwal and Arora, 2006; Dhaliwal and Koul, 2010) [15, 20, 70, 55, 41, 13, 16]. There has been further shift in the status of several insect pests after the introduction of transgenic crops and the current scenario of climate change. Temperature is probably the single most important environmental factor influencing insect behaviour, distribution, development, survival, and reproduction. Some researchers believe that the effect of temperature on insects largely overwhelms the effects of other environmental factors (Bale *et al.*, 2002) [8]. It has been estimated that with a 2ºC temperature increase, insects might experience one to five additional life cycles per season (Yamamura and Kiritani, 1998) [77]. Other researchers have found that moisture and CO_2 effects on insects can be potentially important considerations in a global climate change setting (Coviella and Trumble, 1999; Hunter, 2001) [10, 30]. For every insect species there is a range of temperature within which it remains active from egg to adult stage. Lower values of this range are called 'threshold of development' or 'developmental zero'. Within the favourable range, there is an optimum temperature at which most of the individuals of a species complete their development. Exposure to temperatures on either side of the range exerts an adverse impact on the insect by slowing down the speed of development.

Crop wise changes in insect pest problems

Cotton:

The pest scenario in cotton ecosystem has changed significantly and is assailed by multitude of pests as it evolves through various production levels. American and spotted bollworms attained secondary pest status, and tobacco caterpillar, pink bollworm, mirids, yellow mites and mealy bugs are emerging as major pests. Sap sucking pests like aphids, jassids, thrips and whiteflies are major pests and economically important. Adoption of Bt cotton has not only changed the cultivation profile, but also the pest scenario. While there is a decline in the pest status of bollworms; the sap feeders, *viz.,* aphids, jassids, mirids and mealy bugs are emerging as serious pests (Vennila, 2008) [74]. Recently, mirid bugs, *Ragmus* spp. and *Creontiades biseratense* (Distant) appeared in epidemic form in Dharwad and raichur (Karnataka) and Coimbatote (Tamil Nadu). Also, some of the minor pests like thrips, *Thrips tabaci* Linderman; shoot weevil, *Alcidodes affaber* Aurivillius and stem weevil, *Pempherulus affinis* (Faust) are becoming serious on Bt cotton (Sarode *et al.*, 2009) [64].

Various species of mealy bugs have started appearing in serious proportions on field crops, vegetables, fruits and ornamentals (Tanwar *et al.,* 2007) [73]. In fact, mealy bugs have become indicator insects for the current ecosystem alterations due to slow changes in climate during the period from 2002 to 2005. Among these, *Phenacoccus solenopsis* Tinsley on cotton and *Paracoccus marginatus* Williams and Granara de Willink on papaya have become quite serious. The papaya mealy bug, *P. marginatus,* has become quite alarming in Tamil Nadu, challenging the pesticides and other IPM measures. *Maconellicoccus hirsutus* (Green) causes extensive damage to ornamentals, though its host range extends to 76 families and over 200 genera, including beans, *Chrysanthemum*, citrus, coconut, coffee, cotton, *croton*, cucumber, grape, groundnut, guava, *Hibiscus*, maize, mulberry, pumpkin and rose (Tanwar *et al.,* 2007; Rajendran, 2009) [73, 57].

The mealy bug, *P. solenopsis* was observed for the first time on cotton in USA by Fuchs *et al.* (1991) [25]. It was recorded on *Solanum muricatum* in Chile (Larrain, 2002) [44] and tomato in Brazil (Culik and Gullan, 2005). This insect has also been reported for the first time from Nigeria, Benin and Camaroon in West Africa; Pakistan, Thailand and Taiwan in Asia and from New Cabedonia in the Pacific (Hodgson *et al.,* 2008) [29]. Abbas *et al.* (2005) [1] also reported *Phenacoccus gossypiphilious* Stanley (considered to be misnomer), severely infecting cotton crop in the cotton growing provinces of Pakistan in 2005. During 2006, *P. solenopsis* appeared for the first time on cotton crop in Punjab and caused severe losses in some pockets of Ferozepur, Muktsar and Bhatinda districts (Dhawan and Saini, 2009) [22]. Since then this pest has spread to several states like Haryana, Rajasthan, Maharashtra and Gujarat and southern states (Atwal and Dhaliwal, 2009; Nagrare *et al.,* 2009) [5, 50]. Besides cotton, *P. solenopsis* has been recorded on several economic crops like okra, tomato, brinjal, chilli, grape, fig, date palm, apple, avocado, banana, citrus, etc. (Mohindru *et al.*, 2009) [7]. Recently, a nymphal parasitoid, *Aenasius bambawalei* Hayat, of *P. solenopsis* has been recorded (Hayat, 2009) [28], which caused upto more than 80 per cent parasitization on cotton (Ram *et al.*, 2009) [58, 59, 60] and 30 per cent on tomato (Mohindru *et al.,* 2009) [7].

Helicoverpa armigera (Hubner) had become a menace in pulse growing regions and started causing considerable damage to chickpea and pigeonpea. The last epidemic of *H. armigera* on these crops was reported in 2001. However, after the introduction of Bt cotton in 2002 and its subsequent rapid adoption, its infestation in these crops has significantly declined in the cotton-based cropping systems. *H. armigera* sequently moves from cotton to pigeonpea and then to chickpea. As *H. armigera* is not able to survive on Bt cotton, its cycle gets disrupted and there is no significant movement of the pest from cotton-to-pigeonpea-to-chickpea (Bambawale *et al.*, 2009).

As Bt (Cry 1Ac) cotton provide least protection against tobacco caterpillar, *Spodoptera litura* (Fabricius), it continues to inflict economic damage in several cotton growing regions of India. Recently, there was an outbreak of *S. litura* on soybean in Kota region of Rajasthan and a loss of Rs 300 crore was estimated. The pest also struck in epidemic form on soybean in Vidarbha region of Maharashtra in August 2008 and caused widespread losses (Dhaliwal and Koul, 2010) [13]. Moreover, the intensity of *S. litura* is likely to further increase under the potential climate change, as it has been found to consume more than 30 per cent cotton leaves at elevated CO_2 levels (Kranthi *et al.*, 2009) [37]. Outbreaks of *S. litura* were also noticed in major sunflower growing areas of Central and Southern India. During 2005, the outbreak of *S. litura* led to more than 90 per cent defoliation of sunflower cultivar germplasm (Sujatha and Lakshminarayana, 2007) [71].

In India, *P. gossypiella* incidence has been on the rise. Patil *et al.* (2007) [52] 24 reported an increase in locule damage in the

Raichur area of Karnataka from 44.8 per cent during 2001–2002 to 62.6 per cent in 2004–2005. High incidence of *P. gossypiella* larvae was reported in Haryana (Kumar and Saini, 2005) [42].

The All-India Coordinated Cotton Improvement Project (AICCIP) reported high catches of *P. gossypiella* with pheromone traps in Gujarat, especially at Surat and Junagarh, during the last week of November 2009 to January 2010, and in Rajasthan at Sriganganagar from August to October 2009, as compared with ten other locations in the country. The presence of larvae in green bolls of Bt cotton has also been reported in some locations in the country (private communication, http://www.cicr.org.in). However, on 6 March 2010, Monsanto India Limited reported pink bollworm resistance to Bt cotton producing Cry1Ac planted in 2009 under field conditions in four districts of Gujarat, namely Amreli, Bhavnagar, Junagarh and Rajkot, on the basis of bioassays and the presence of larval incidence and damage to Bt cotton (www.monsantoindia.com). The data reported here constitute the first evidence of field-evolved resistance of pink bollworm to Cry1Ac and this initial evidence spurred more extensive evaluations during the 2009–2010 growing season, which confirmed field-evolved resistance to Cry1Ac in Amreli. The lack of cross-resistance to Cry2Ab2 suggests that plants producing this toxin are likely to be more effective against resistant populations than plants producing only Cry1Ac (Sanyasi Dhurua and Govind Gujar, 2011) [63].

Cotton plantations in Punjab have come under a major ‘Whitefly’ attack, triggering fears of a massive yield loss in the Kharif crop in the State. With cotton growing areas witnessing the “worst” attack of whiteflies in past five years, experts are blaming humid weather conditions for the widespread attack. Total area under cotton crop in Punjab is about 4.5 lakh hectares and is mainly grown in Fazilka, Bathinda, Mansa, Muktsar and Abohar. Muktsar district alone accounted for 2,400 hectares of the total crop loss. The next highest percentage of total crop loss was reported in Fazilka with 907 hectares affected. In Bathinda district, crop on 836 hectares was completely damaged. Over all whitefly attack in Punjab that damaged over 75 per cent crop across the cotton belt. The damage to the cotton crop, over 95 per cent of which is Bt cotton, is estimated to be around Rs. 4,500 crore. It is also being blamed as a reason for suicides of over a dozen farmers in the cotton belt, including Abohar, Fazileka, Bathinda and Muktsar districts (Anonymous, 2015) [3].

Pigeonpea

More than 250 species of insects have been found feeding on pigeonpea, although only a few of these cause significant and consistent damage to crop *viz.,* web forming or spotted pod borer, *M. vitrata,* the gram pod borer, *Helicoverpa armigera* (Hubner) and the pod fly, *Malanagromyza obtusa* Malloch are the major pest species inflicting damage to pods. Spotted pod borer, *M. vitrata* is becoming predominant insect pest in recent years in all pigeonpea growing areas of India. This pest is a single major factor responsible for heavy loss in early and medium late maturing pigeonpea genotypes (Sahoo, 1995; Shanower *et al.,* 1999) [62]. Larvae feed by remaining inside the webbed mass of leaves, flowers and pods. This concealed feeding complicates the management of this pest as pesticides and natural enemies have difficulty in penetrating the shelter to reach the larvae (Sharma, 1998) [66]. Pigeonpea genotypes with determinate growth habit, where pods are bunched together at the top of the plant are more prone to damage than in the indeterminate ones (Sharma *et al.,* 1999) [67]. With the introduction of short duration genotypes for cultivation, Maruca has emerged as one of the major constraint because of the coincidence of high humidity and moderate temperature in September – October coinciding with the flowering of the crop in India. Recently shift in the sucking pests mainly leafhoppers on pigeonpea was noticed which recorded 13.60 leafhoppers/ three leaves and whereas thrips incidence was found to be 12.24 per flower (Lingaraju and Biradar, 2015) [45].

Paddy

Stem borer incidence was low upto 1970s, moderate till 1975 and severe and widespread from 1980 onwards and still remains as a major rice pest. BPH not considered as a pest till 1970s assumed major pest status from 1990s to till date. Moderate incidence due to WBPH is reported since 2000 and potential pest to assume serious proportions in the coming decade, particularly in irrigated ecologies. Leaf folder moderate till eighties, has become a serious pest in the recent decades. Gall midge is maintaining its status and through evolution of new biotypes may pose major problems in future. Armyworm, Hispa, Caseworm and whorl maggot incidences increased since 2000 in localized areas. Green leafhopper and grasshoppers at low ebb from 1985- 2000 are increasing in proportions in the recent years. The number of rice pests has increased from 3 to 15 since 1965 to 2009, apart from some more pests of regional significance (Krishnaiah and Varma, 2010) [38].

Recently, Brown planthopper (*Nilaparvata lugens)* became serious pest and its first serious epidemic of BPH occurred in 1973 over half a million ha resulting in 10-70 per cent loss in grain yield in Indian condition. Series of BPH outbreaks since then were recorded in Karnataka (1975 and 1985), in Andhra Pradesh (1976-1983) and Telangana (1980), Madhya Pradesh and Orissa (1976), Tamil Nadu (1977 and 1982). Large scale cultivation of gall midge resistant varieties gave alarming reports of development of new biotypes damaging gall midge resistant varieties received from Andhra Pradesh and Maharastra during the last decade. It was also reported to have caused heavy losses in Java, Indonesia. The widespread epidemics of rice hispa were reported in Orissa, H.P., W.B. and Tripura during 60s and 70s. Yellow stem borer is a key pest of rice, causing losses upto 95 per cent until 1960s. The pest declined in severity during 1970s due to large scale cultivation of dwarf rice varieties (Krishnaiah, 1993) [39]. A serious problem in Andhra Pradesh and Tamil Nadu, particularly in areas cropped with BPH-resistant varieties. The pest reduces yield by 40-57 % (Kataki, 2001) [34].

Over all Yellow stem borer (YSB), leaf folder and BPH in West Bengal, Termites and mealy bugs in Bihar, rice hispa in Uttar Pradesh, BPH and WBPH in Haryana, Pink stem borer and leaf folder in Punjab, YSB, BPH, rice hispa and root grub in Orissa, Leaf folder and GLH in Madhya Pradesh, gundhi bug in Maharashtra, Army worm and Leaf folder in Gujarat, Leaf folder, whorl maggot and panicle mite in Andhra Pradesh, gundhi bug and gall midge in Karnataka and leaf folder, leaf mite, rice black bug and Army worm in Tamil Nadu have become important because of their changing status during 2006-2009 (Mangal Sain and Prakash, 2008) [46].

Rice sheath mite, *Steneotarsonemus spinki* Smiley (Acari: Tarsonemidae) infests flag leaf sheath and causes brown discolouration, also its infestation on panicle causes chaffy grains and discolouration of filled or ill-filled grains. Feeding of these mites on reproductive parts of flowers results in grain sterility and this mite has also been reported as vector/carrier of pathogenic fungi like Acrocylindrium (Sarocladium) oryzae, *Fusarium moniliforme*, Helminthosporium oryzae, etc. Recently, in India this mite was observed to cause significant reduction in yield of rice crop in Gujarat and West Bengal (Anonymous, 2007-09) [2] and also It has been reported from East and West Godavari districts of Andhra Pradesh (Rao *et al.*, 2000) [61], Gujarat (Bandhania & Purohit, 2007) [9], West Bengal (Anonymous, 2007-09) [2] and Karnataka (Prabhakara, 2002; Mutthuraju, 2010) [53, 49].

Maize, sorghum and millets:
The maize stem borer (*Chilo partellus*) is a traditional destructive pest of maize and sorghum causing 20-87 per cent loss in yield under varied agroclimatic conditions. The shootfly (*Atherigona* spp.) was a minor pest of maize throughout the country except in parts of Southern India. Heavy incidence of Pyrilla was recorded on grain and fodder sorghums in the entire northern belt of the country (Kishore Prem, 2005) [36].

The varieties and hybrids developed during green revolution era in sorghum and pearl millet are better in quality parameters than traditional locals but are highly susceptible to insect pests. The key pest shootfly, *Atherigona soccata* Rondani, did not pose any serious problem before sixties as the tolerance of the local cultivars was able to contain this pest. Similarly classical example is that of midge, *Stenodiplosis sorghicola* (Coquillet) incidence in Maharashtra State. Continued flowering from early maturing hybrids to late locals in the same area enabled rapid multiplication of midge which could be controlled by en bloc coverage or Maharashtra State by varieties which flowered about the same time. The earhead bug, *Calocoris angustatus* Lethiery; gram pod borer, *Helicoverpa armigera* Hubner are other pests which became serious on sorghum after sixties. Recently, the grey weevil, *Myllocerus* spp. and sugarcane lear hopper, *Pyrilla perpusilla* Walker have assumed pest status on sorghum and pearl millet. The grey weevil attacks the crop both at early and late stages of development. Heavy incidence or Pyrilla was recorded on grain and fodder sorghums in the entire northern belt of the country. A perfect hopper burn was also observed on some sorghum varieties at the farm of Indian Agricultural Research Institute, New Delhi. Pearl millet was equally attacked by *Pyrilla*. Need for development of new cultivars endowed with insect resistance is inevitable (Kishore Prem, 2005) [36].

A list of insect and non-insect pests which can assume serious proportions in future due to changes in the ecosystems and habitats is given in Table. Recently, Tabashnik *et al.* (2008) [72] has reported the occurrence of resistance in Bt cotton to *Helicoverpa zea* (Boddie) in Arkansas and Mississippi states of USA. There are also indications of development of resistance in *H. armigera* in parts of China (Wang *et al.*, 2009) [75] and occasional reports of survival of *H. armigera* on Bt cotton in Australia (Downes *et al.*, 2007) [24] and India (Kranthi *et al.*, 2009) [37]. Therefore, *H. armigera* may again reemerge as major pest of cotton if the resistance in Bt cotton breaks down. In addition, some alien and new pests could become invasive and some secondary pests could assume serious proportions. Some of the examples include sugarcane wolly aphid, *C. lanigera*; coconut eriophyiid mite, *Aceria guerreronis* Keifer; coffee berry borer, *Hypothenemus hampei* (Ferrari); sapoda seed borer, *Trymalitis margarias* Meyrick; spiralling whitefly, *Aleurodicus disperses* Russell and serpentine leafminer, *Liriomyza trifolii* (Burgess) (Puri and Ramamurthy, 2009) [56]. The recent epidemic of *S. litura* on soybean in Vidarbha region of Maharashtra in August 2008 and outbreak of brown plant-hopper, *Nilaparvata lugens* (Stal) on basmati rice in Haryana and Western Uttar Pradesh during September- October 2008, were mainly due to favourable prevailing weather conditions (Bambawale *et al.*, 2009)

Table 1: Crop loss (%) due to insect pests during pre and post green revolution in India

Crop	Pre-green revolution (early 1960s)	Post-green revolution (early 2000s)	Changes in loss
Cotton	18.0	50.0	+32.0
Groundnut	5.0	15.0	+10.0
Other oilseeds	5.0	25.0	+20.0
Pulses	5.0	15.0	+10.0
Rice	10.0	25.0	+15.0
Maize	5.0	25.0	+20.0
Sorghum and millets	3.5	30.0	+26.5
Wheat	3.0	5.0	+2.0
Sugarcane	10.0	20.0	+10.0
Average	7.2	23.3	+16.1

(Dhaliwal *et al.*, 2007) [21].

Crop Losses
Losses due to insect pests in Indian agriculture have been estimated from time to time (Pradhan, 1964; Krishnamurthy and Murty, 1983; Atwal, 1986, Jayaraj, 1993; Lal, 1996; Dhaliwal and Arora, 1996, 2002; Dhaliwal *et al.*, 2003, 2004) [54, 40, 6, 32, 43, 14, 15, 20, 18, 19]. In general, the losses in post-green revolution era (Dhaliwal *et al.*, 2004) [19] have shown an increasing trend than in the pre-green revolution era (Pradhan, 1964) [54]. Overall, the losses increased from 7.2 per cent in early 1960s to 23.3 per cent in early 2000s (Table). The maximum increase in loss occurred in cotton (18.0 to 50.0 %), followed by other crops like sorghum and millets (3.5 to 30.0 %), maize (5.0 to 25.0 %) and oilseeds (other than groundnut) (5.0 to 25.0 %). There has been a paradigm shift in the crop management scenario of Indian agriculture since the beginning of this century. Bt cotton was released in the country in 2002 and later the area under Bt cotton increased significantly.

Reasons for the change in insect pest problems:
The factors contributed for the change in pest scenario of different pest are the use of high yielding varieties, monoculture practices, excessive use of fertilizers and indiscriminate use of pesticides, expansion of irrigation facilities and modification of cultural practices. Following are the important factors which expected to contribute towards the future changes in pest problems:

Impacts of climate change on insect-pests

Loss of ecological biodiversity

In the present day scenario, many butterfly species are under a real threat due to depletion of the natural vegetation for various anthropogenic developmental activities (Sidhu and Mehta 2008) [69].

Expansion of geographic ranges

The insect-pests are expected to extend their geographic range from tropics and subtropics to temperate regions, which lead to increased abundance of tropical insect species and sudden outbreaks of insect-pests (Kannan and James, 2009).

Physiological and Ecological Impact

Some of the species that are able to adapt to the warmer climates may become major pests (Dillon *et al.,* 2010) [23]. Differences in the pattern of response to temperature changes would disrupt synchronization in phenology between insects and host plants or natural enemies (Kiritani, 2006) [35].

Increased overwintering survival

The temperature in India is expected to increase by 1-5^{0}C within next 100 years (Arora and Dhawan 2013) [4]. Insects undergoing a winter diapause are likely to experience the most significant changes in their thermal environment (Bale and Hayward 2010) [7]. Increase in temperature in the range of 1-5^{0}C would increase insect survival (Sharma *et al.,* 2010) [68].

Increase in number of generations

With every 2ºC rise in temperature, multivoltine insects may have 1-5 additional generations (Yamamura Kiritani, 1998) [77]. Rice stem borer *Chilo suppressalis* would extend its distribution range in Japan and produce two generations a year after 2^{O}C warming (Morimoto *et al.,* 1998) [48].

Changes in Insect Feeding

Insects have been shown to feed more when plants are grown in elevated levels of carbon dioxide (Hamilton *et al.,* 2005) [27]. Sap-feeders were the only functional group to show positive responses to elevated CO_2 with increased food consumption and higher build up at higher CO_2 levels (Whittaker, 1999) [76].

b) Introduction of transgenic crops

Introduction of transgenic crops decline the status of major pest but the population of minor pest increases. The pest scenario in cotton ecosystem is changing and sap feeder like aphids, jassids, mirid and mealy bugs are emerging as serious pest (Vennila 2008) [74]. *Spodoptera litura* and other minor pest of cotton thrips and weevil are also becoming serious pest of cotton (Sarode *et al.,* 2009) [64].

c) Changes in tillage technology

Zero tillage, Rotary tillage, and bed planting contributed new pest problems in wheat. Direct seeded rice may also result in change in the pest complex of rice.

Conclusions

With the development of agricultural technology as well as biotic and abiotic factors, the crop losses and insect pest problems are changing continuously. Future research should focus on the gaps in our knowledge, especially regarding pest behaviour and the characteristics of insect resistance that we do not yet fully understand. This will lead to more reliable management programs. Globally, it is understood that there is an increase in temperatures which has a significant impact on the precipitation also. These abiotic factors influence the biology and population dynamics of the pests at the micro level. The change in cultivation practices also alters the microenvironment which is the niche for many of the biotic agents. Hence, a thorough understanding of the system *per se* and integration of both production and protection systems is essential for sustainable production. There is a need to explore certain reformative measures to narrow down these losses.

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