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Climate change effects on pest spectrum and incidence in grain legumes

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Abstract

Global warming and climate change will influence activity, diversity, distribution and population dynamics of insect pests including the grain legumes. Several insect pests damage grain legume crops, of which the pod borer, *Helicoverpa armigera*; spotted pod borer, *Maruca vitrata*; spiny pod borer, *Etiella zinckenella*; pod fly, *Melanagromyza obtusa*; aphid, *Aphis craccivora*; defoliators, *Spodoptera litura* and *S. exigua*; thrips, *Megaleurothrips usitatus* and *Caliothrips indicus* and the bruchid, *Callasobruchus chinensis* cause extensive losses in grain legumes. The incidence and extent of losses due to these pests varies across seasons, locations, and cropping systems. The pest spectrum on grain legumes will change considerably due to impending global warming and climate change. The geographical distribution of some of the pests might extend to temperate regions in Europe and America, while the outbreaks of some other pests will become more frequent. Several outbreaks of pod borer, *H. armigera* and spotted pod borer, *M. vitrata* have been recorded on grain legumes in India, which at times have resulted in complete crop loss. The scale insect, *Ceroplastodes cajani* in pigeonpea and beet armyworm, *Spodoptera exigua*, mealy bug, *Ferrisia virgata*, and white fly, *Bemisia tabaci* in chickpea have emerged as new pests; while leaf miner, *Porphyrosela neodoxa*, mealy bugs, *Drepanococcus cajani*, and *Coccidohystrix insolita* are some of the emerging pest problems in pigeonpea in India. In addition, there will be greater genotype x environment interactions for expression of resistance to insect pests, and this warrants a greater effort for identification of diverse sources of resistance and need for integrated pest management packages that will be effective under global warming and climate change.

Key words: Chickpea, Climate change, Grain legume, Pest management, Pigeonpea

Grain legumes play an important role in cropping systems and soil health. They are a principal source of dietary protein, and are an integral part of daily diet in several forms worldwide. In addition to their nutritional value, the pulses also help to fix atmospheric nitrogen and add organic matter to the soil. Pulses provide significant nutritional and health benefits, and are known to reduce several non-communicable diseases such as colon cancer and cardiovascular diseases (Jukanti *et al.* 2012). Grain legumes are cultivated globally on an area of 70.00 million hectares, with a total production of over 78.00 million tons, the average productivity being 846 kg ha^{-1} (FAO 2012). Worldwide, chickpea and pigeon pea are the two major food legumes, cultivated on an area of 11.00 and 4.70 million ha, respectively. The total production being 9.00 and 3.75 million tons, with an average productivity of 826 and 720 kg ha^{-1}, respectively (Akibode and Maredia 2008).

India is the largest producer and consumer of pulses in the world. Chickpea (*Cicer arietinum* L.), pigeonpea (*Cajanus cajan* (L.) Millsp., lentil (*Lens culinaris* Medik.), urdbean (*Vigna mungo* L.), mungbean (*Vigna radiata* L.), lablab bean (*Lablab purpureus* L.), moth bean (*Vigna aconitifolia* Jacq.) Marechal), horse gram (*Dolichos uniflorus* Lam.), pea (*Pisum sativum* L.), grasspea (*Lathyrus sativus* L.), cowpea (*Vigna unguiculata* L.), and faba bean (*Vicia faba* L.) are the important pulses grown in India. Chickpea, pigeonpea, mungbean, urdbean and lentil are the major pulses, of which chickpea is the most dominant accounting for 40% of the total pulse production, followed by pigeonpea (20%), mungbean (11%), urdbean (102%), and lentil (9%) (Anonymous 2011). In India, the total pulse production for the year 2013-14 was 18.43 million tons on an area of 26 million ha, with an average productivity of 758 kg ha^{-1} (Anonymous, 2015). India's population would reach 1.68 billion by 2030 from the present level of 1.21 billion. Accordingly, the projected pulse requirement for the year 2030 is 32 million tons with an anticipated required growth rate of 4.2% (Anonymous, 2011). Major areas under pulses are in the States of Madhya Pradesh (20.3%), Maharashtra (13.8%), Rajasthan (16.4), Uttar Pradesh (9.5%), Karnataka (9.3%), Andhra Pradesh (Telangana and Andhra Pradesh) (7.9%), Chhattisgarh (3.8%), Bihar (2.6%) and Tamil Nadu (2.9%) (Anonymous 2009).

Increased heat stress, shift in monsoons, and drier soils pose a greater threat to production of grain legumes in the tropics than in the temperate regions (Rosenzweing and Liverman 1992). The relationship between the inputs costs and the resulting benefits will change as a result of changes in insect-plant interactions. This will have a major bearing on economic thresholds, as greater variability in climate will result in variable impact of pest damage on production of grain legumes. Increased temperatures and UV radiation, and low relative humidity may render many of these control tactics to be less effective, and therefore, there is a need to address these issues on an urgent basis for sustainable crop protection and food security.

Global warming and climate variability will result in a drastic reduction in food production, and have major bearing on pest spectrum damaging these crops, and the extent of crop losses due to insect pests. The fifth assessment report of the Inter-Governmental Panel on Climate Change (IPCC 2014) indicated a temperature rise of 0.85 [0.65 to 1.06] °C between 1880 and 2012. Global atmospheric concentration of CO_2 has increased from the pre-industrial value of 280 ppm to 401 ppm in 2015 (Mauna Loa Observatory: Hawaii), and are anticipated to double by the end of the 21st century. As a result of global warming, many terrestrial, freshwater, and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to climate change (IPCC 2014).

Mean annual temperature changes are estimated of between 3 and 6°C to occur across Europe, with the greatest increases occurring at high latitudes (IPCC 2014). Weather factors such as temperature, relative humidity and rainfall play a vital role in multiplication and distribution of insect pests. Number of generations or seasonal abundance is mostly influenced by temperature, host selection and host suitability. Rainfall directly and indirectly influences seasonal abundance of insect pests by affecting the abundance and suitability of host plants. To develop a robust pest management program to mitigate the effects of climate change, there is a need for information on species composition, relative abundance and distribution of insect pests in relation to weather factors (Patel and Shekh 2006).

The pest associated losses are likely to increase as a result of changes in crop diversity and climate change. Climate change and climate variability will have major implication for water availability, forest cover, biodiversity, crop production, and food security. Changes in rainfall pattern are of greater importance for agriculture than the annual changes in temperature, especially in regions where lack of rainfall may be a limiting factor for crop production. Changes in the geographical distribution of tropical and subtropical insect pests will extend along with shifts in the areas of production of their host plants, while distribution and relative abundance of some insect species vulnerable to high temperatures in the temperate regions may decrease. High mobility and rapid population growth will increase the extent of losses due to insect pests (Sharma 2014). Climatic changes/variability might result in:

- Extension of geographical distribution.
- Increased/decreased over-wintering, number of generations, and population growth rates.
- Changes in crop-pest and interspecific interactions.
- Increased risk of invasion by migrant pests.
- Changes in crop-pest synchrony and introduction of 'green bridges'.
- Changes in effectiveness of crop protection technologies.

These changes will have major implications for crop production and food security, particularly in the developing countries in the semi-arid tropics, where the need to increase and sustain food production is the most urgent.

Changes in pest spectrum in pigeonpea and chickpea in relation to cropping patterns and climate change

The relative importance of insect pests on grain legumes will change under global warming and climate change (Sharma *et al.* 2010). Information on insect pests damaging pigeonpea and chickpea over the past 100 years has indicated a wide variation in pest spectrum between 1900 - 1950, 1951 - 1975, 1976 - 2000 and 2001 to till date, in relation to changes in cropping patterns and climate change. The major changes in pest spectrum and pest outbreaks have been listed in Tables 1 and 2. More than 250 insect species have been recorded feeding on pigeonpea and chickpea, although only a few of them cause significant and consistent damage (Sharma *et al.* 2010). Twelve new insect pests/ pest outbreaks have been recorded on pigeonpea, of which legume pod borer, *H. armigera*, spotted pod borer, *M. vitrata* (Geyer) and pod sucking bug, *Clavigralla* spp. have resulted in complete crop loss in certain regions/ years.

Table 1. New records of insect pests/ pest outbreaks on pigeonpea in India

Insect pest	Location	Reference	Remark
White tailed mealy bug, *Ferrisia virgata* (Cock.)	Delhi (Oct-Nov 1984)	Gautam and Saxena (1986)	New pest
Pod borer, *H. armigera* (Hubner)	Guntur, Andhra Pradesh (1977-78)	Ranga Rao and Shanower (1999)	Temperature and unseasonal rains resulted in outbreak
Cydia critica Meyrick	Eastern Uttar Pradesh (1982-83)	Shukla *et al.* (1984)	New pest
Lepropus lateralis Gyllenhal	Eastern Uttar Pradesh (1982-83)	Shukla *et al.* (1984)	New pest
Myllocerus Undecimpustulatus Faust	Eastern Uttar Pradesh (1982-83)	Shukla *et al.* (1984)	New pest
Nanaguna breviuscula Walker	Orissa (1982)	Samalo and Patnaik (1984)	New pest
Mealy bug, *Ceroplastodes cajani* Maskell	Gujarat (1989/90)	Patel *et al.* (1991)	Rainy season
	Nimar region (Madhya Pradesh) (Sep- Dec 1992)	Shaw *et al.* (1999)	Long dry spell, High temperature
	Vamban, Tamil Nadu (1993)	Ganapathy *et al.* (1994)	
Pod weevil, *Apion clavipes* Gerst.	Muzafarpur and Samastipur (Bihar) (1979-80)	Sinha and Yadav (1983)	
	West Bengal (2001-2003)	Bandyopadhyay *et al.* (2009)	
Coccidohystrix insolitus Ferris.	Vamban, Tamil Nadu (1993)	Ganapathy *et al.* (1994)	
Alcidodes collaris Pascoe	Dharwad (Karnataka) 1999	Giraddi *et al.* (2000)	
Spotted pod borer, *Maruca vitrata* Fab.	Dharwad (Karnataka) 1999	Giraddi *et al.* (2000)	Heavy loss
	Northern, Madhya Pradesh (1996)	Singh (1997)	
Crab caterpillar (*Neostauropus alternus* Walker)	South India	NBAIR	Initially minor in south India and now becoming major in north India
Stem borer or longhorn beetle (*Batocera rufomaculata* DeGeer)	Anantapur (Andhra Pradesh)	Nagamani *et al.* (2015)	New pest

Table 2. Major insect pests/ pest outbreaks recorded on chickpea in India

Common Name	Scientific Name	Distribution	Severity of damage	Impact of climate change on insect species
Chickpea pod borer	*H. armigera*	Widely distributed in India	XXX	Severe outbreaks are associated with rains in Oct - Jan
Termites	*Odontotermes* sp.	Causing significant damage in north India	XX	Long dry spells result in greater damage
Cutworm	*Agrotis segetum* Denis & Schiffermüller	All India	XX	Heavy infestations occur following flooding in Indo-Gangetic plains
Beet armyworm	*Spodoptera exigua* Hubner	South India	XXX	Emerging as a major pest following unseasonal rains in Oct – Nov in southern India
Black aphid	*Aphis craccivora* Koch	All India	XX	Rains during the cropping season increase aphid and virus infestation
Semi-looper	*Autographa nigrisigna* Walker	North India	X	
White grub	*Lachnosterna* [*Holotrichia*] *consanguinea* Blanch	Causes significant damage in light sandy soils in Rajasthan and Gujarat	X	
Leaf minor	*Liriomyza cicerina*	Causes significant damage Kabuli and broad leaf cultivars	X	
Root beetle	*Gonocephlum* spp.	Occasionally feed on seedling roots ultimately drying of plants.	X	

XXX= Highly serious pest, XX = Serious, and X = Occasional pest.

Change in geographic distribution

Low temperatures are often more important than higher temperature in determining global geographical distribution of insect pests and diseases (Hill 1987). Therefore, for species which are currently limited by low temperature, increasing temperature may result in greater ability to overwinter at higher latitudes and may increase a pest chance of extending its range (Hill and Dymoch 1989). Populations of the corn earworm, *Helicoverpa zea* (Boddie.) in the North America might move to higher latitudes/altitudes, leading to greater damage in maize and other crops (EPA 1989). The pod borers, *H. armigera* and *M. vitrata,* which are confined to tropics, may extend their range of geographical distribution to northern Europe and America (Sharma *et al.* 2015).

Effect of climate change on onset of insect infestation

There will be more number of generations due to shortening of development time due to rise in temperature in the tropics. Problems with new insect pests will occur, if climatic changes favor the introduction of susceptible crops or cultivars. The introduction of new crops/ cultivars to take advantage of the new environmental conditions is one of the possible responses to climate change (Parry and Carter 1989). Many insects such as *Helicoverpa* spp. are migratory, and therefore, may be well adapted to exploit new opportunities by moving rapidly into new areas as a result of climate change (Sharma

2005). Overwintering of insect pests will increase as a result of climate change, producing larger spring populations as a base for a build-up in numbers in the following season. Global warming will lead to earlier infestation by insect pests such as *H. zea* in North America (EPA 1989). Early termination of diapause due to global warming will lead to earlier infestation by *H. armigera* in North India (Sharma 2010), resulting in increased crop loss.

Effect of climate change on pest incidence in grain legumes

Pigeonpea sown during August suffered maximum insect damage, followed by the crop sown in July (Fig. 1). Minimum pest incidence was recorded in the crop sown in September. The pod borer, *H. armigera* larval population ranged from 5.40 - 7.39 larvae/plant, and the August sown crop recorded maximum population of *H. armigera* larvae. The *Grapholita critica* Meyr. population was lower (1.36/plant) in the late sown crop in September as compared to the normal sown crop in June – July (2.03-2.79 larvae/plant). Incidence of plume moth larvae was high at the flowering stage, and maximum incidence (8.39 larvae/ plant) was recorded in the crop sown in June. Incidence of thrips, *Megaleurothrips usitatus* (Bagnall) was high in the third sowing (14.57 thrips/plant). ICPL 332 WR, which has moderate levels of resistance to *H. armigera,* showed a susceptible reaction to pod borer, *H. armigera* in the crop sown during August (6.64 larvae/ plant). The population of coccinellid predators was highest in the September sown crop, and maximum numbers of coccinellids were recorded on ICPL 88039 (7.05 larvae/plant), followed by ICPL 98008 (6.70 larvae/plant) at the pod setting stage. The results indicated that the incidence and severity of different insect pests varied across cultivars and planting dates.

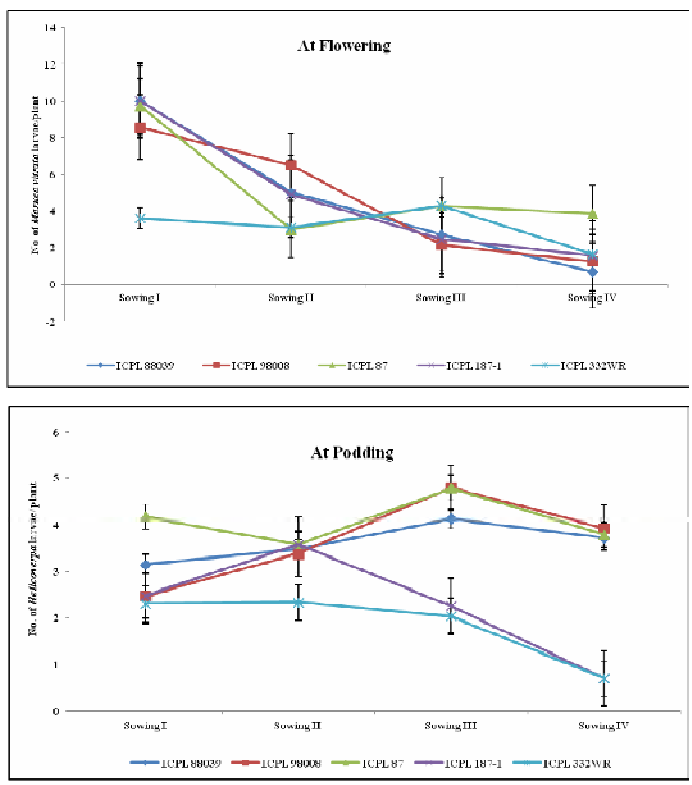

Fig. 1 Incidence of spotted pod borer, *M. vitrata* at flowering, and legume pod borer, *H. armigera* at the podding stage in five genotypes of pigeonpea in relation to temperature and RH across planting dates under field conditions.

Incidence of pod borers, *H. armigera* and *S. exigua* in chickpea during the 2012-13, post rainy seasons varied across genotypes and sowing dates (Fig. 2). Leaf damage by *H. armigera* and *S. exigua* was greater in the October sown crop [average leaf damage rating (DR) of 2.67] than the November sown crop (DR 0.53). The abundance of *H. armigera* larvae was maximum in the October sowing (14.4 larvae/5 plants) and lowest in the January sown crop (2.81 larvae/5 plants), and this might be linked to greater crop canopy/biomass in the early sown crops. The incidence of *S. exigua* larvae was maximum in the January sown crop (3.2 larvae/5 plants) and lowest in the November sown crop (0.19 larvae/5 plants). Across genotypes, highest numbers of *H. armigera* larvae (10.4 larvae/5 plants) were recorded on ICC 3137, followed by KAK 2 (8.6 larvae/5 plants), ICCL 86111 (8.32 larvae/5 plants), JG 11 (7.75 larvae/5 plants) and ICCV 10 (5.63 larvae/5 plants). The abundance of *S. exigua* larvae was highest in KAK 2 (2.49 larvae/5 plants) and lowest in JG 11(1.48 larvae/5 plants). There were no significant differences in abundance of *S. exigua* larvae among the genotypes tested. Incidence and damage of pod borer, *H. armigera* in chickpea was highest regarding pod damage (22.82%) in October sown crop, and the lowest (11.76%) in November sown crop in 2003-04; whereas in 2004-05, highest pod damage (27.36%) was observed in October, and lowest (20.16%) in November sown crop in Pakistan (Altaf *et al.* 2008). Late sown chickpeas at high plant densities were highly damaged by *H. armigera*, but the yields were higher than for early sown crops (Begum *et al.* 1992). Incidence of pod borer, *H. armigera* started in 2nd to 4th week of January, pod borer population was higher in the early sown crop (October 15 to November 01) (Hossain *et al.* 2009). Delayed sowings from November 01 to November 30 suffered less damage, but the incidence increased again. Both the early (October 15 to November 01) and late sown (December and onwards) crops exhibited high pod borer

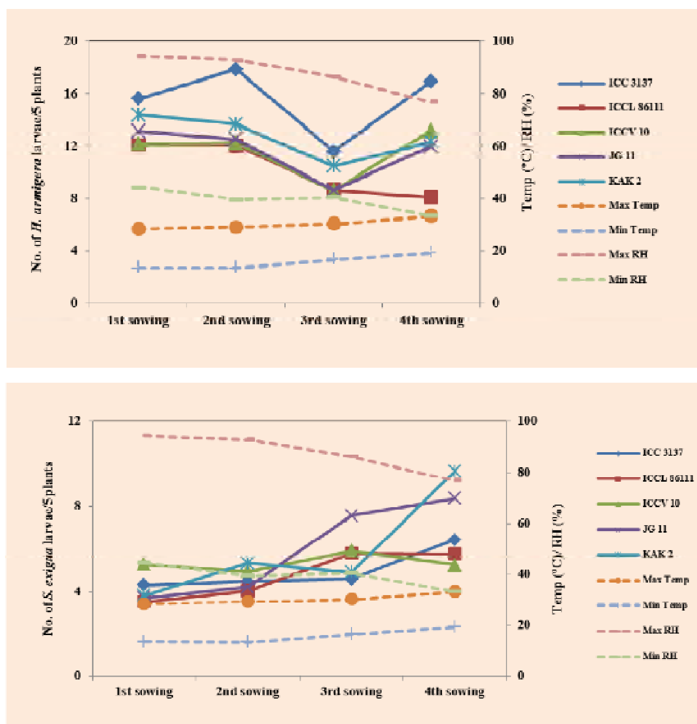

Fig. 2. Incidence of *H. armigera* (a) and *S. exigua* (b) in relation to temperature and RH on different genotypes of chickpea across planting dates under field conditions.

damage and produced lower grain yield, but mid-sown (November 08 to 30) crops recorded less pod borer damage and produced higher yield.

Effect of climatic factors on insect development and population dynamics

Rising temperatures are likely to result in availability of new niches for insect pests. Emergence of some insect pests from diapause might occur much earlier than their natural enemies, resulting in a mismatch between the interacting species. Temperature has a strong influence on the viability and incubation period of *H. armigera* eggs, which can be predicted on day degrees required for egg hatching (Dhillon and Sharma 2007). The developmental time of the *H. armigera* larvae decreased from 24.57 days at 25^{0}C to 18.27 days at 30^{0}C (Bartekova and Prashicka 2006), suggesting increased number of generations under global warming. The time required from egg to adult varied between 122.6 days at 15^{0}C and 22.5 days at 35^{0}C whereas 25^{0}C along with 70-90% RH was favorable for the development of *H. armigera* (Wu Kunjun *et al.* 1992). There is a negative association between mean temperature and incidence of *H. armigera* (Patnaik and Senapati 1996). Minimum and maximum temperatures have been found to be positively correlated with population of *H. armigera* and *S. exigua* larvae (Sharma 2005; Shah and Shahzad 2005; Upadyaya *et al.* 1989; Pandey *et al.* 2012; Sharma *et al.* 2012). The abundance of *H. armigera* and *S. exigua* larvae is negatively correlated with relative humidity (Sharma 2005).

Moth emergence has been found to be negatively correlated with the maximum and minimum temperatures, but there is no significant relationship between relative humidity and pest incidence (Ugale *et al.* 2011). Minimum temperature and rainfall exert a negative influence on pheromone trap catches of *H. armigera* (Pandey *et al.* 2008). Extreme temperature, humidity and other weather factors (e.g., wind and hailstorm) are thought to be responsible for mortality of eggs, larvae and pupae of most of insect species (Pearson 1958; Qayyum and Zalucki 1987). Populations of *H. armigera* were high during second half of February and observed throughout March owing to optimum temperature and abundant food (Lal 1996). High larval populations occurred during periods of optimum climatic conditions for development (Dakwale and Singh 1980), and flowering and pod formation stages of the crop (Deka *et al.* 1987; Lal 1996; Patel and Koshiya 1999). Infestation of *H. armigera* on chickpea started in the second fortnight of November, and reached its peak by the end of February in North India (Yadav and Jat 2009).

Pest outbreaks in grain legumes

The pest outbreaks have often been related to unusual climatic conditions. Pest outbreaks are more likely to occur on stressed plants as a result of weakening of plants' defense system, and thus, increasing the level of susceptibility to insect pests. Unseasonal rains during October often result in complete loss of crop due to *M. vitrata* (Sharma *et al.* 2010), while heavy rains during Nov – Dec have resulted in high damage by *H. armigera* in southern India. Incidence of *H. armigera* in southern India (Table 3) is influenced by the amount of rainfall during the rainy and the post rainy season (high incidence = +A + B, moderate incidence = -A +B, and low incidence = -A –B; where A = Jun-Sept rainfall, and B = Oct-Nov rainfall) (Das *et al.* 2001).

Table 3: The rainfall during monsoon and November and its relationship with the level of *Helicoverpa attack*

Year	A	B	Moth catch at pheromone trap	Level of attack
1982	-27.3	-11.7	1505	Moderate
1983	+265.6	-22.5	301	Low
1984	-113.1	-17.1	-*	Moderate
1985	-240.0	-23.5	1680	Moderate
1986	-86.4	+13.3	2570	Severe
1987	-177.3	+216.5	2409	Severe
1988	-273.9	-23.5	-*	Moderate
1989	+285.5	-23.5	-*	Low
1990	-91.5	-12.1	1798	Moderate
1991	+36.9	-20.5	913	Low
1992	-55.4	+53.5	2205	Severe
1993	-36.4	-23.5	1391	Moderate
1994	-73.8	-13.9	1122	Moderate
1995	+122.7	-10.5	974	Low

*Complete data not available. Source: Das *et al.* (2001).

Early rise in temperature during March in North India has resulted in *H. armigera* outbreak on pigeonpea and chickpea (Sharma 2014). Heavy damage by the mealy bug, *Ceroplastodes cajani* (Maskell) has been associated with long spells of drought in western India. The papaya mealy bug, *Paracoccus marginatus* (Williams & Granara de Willink), an invasive species, has devastated several crops in southern India, and its infestation has also been recorded on pigeonpea (Sharma HC, Unpublished). Cyclonic storms in Nov - Dec have resulted in heavy damage by the beet armyworm, *S. exigua,* which is an emerging pest of chickpea in southern India. Mealy bugs, *F. virgata* and white fly, *Bemisia tabaci* (Gennadius) have been recorded as new pests on chickpea during the summer months under greenhouse conditions. Emerging pest problems in pigeonpea and chickpea as a result of climate change are presented in plates 1 to 6.

Climate change and pest management in grain legumes

Monitoring of pest populations is the key to determine if a threshold has been exceeded and control measures are required. There will be increased variability in pest incidence as a result of global warming and climate change. Global warming and climatic variability will also influence the expression of host plant resistance to insects, and also affect the effectiveness of transgenic crops to control insect pests (Sharma, 2014).

Therefore, there is need to develop crop cultivars with insect resistance that are stable across locations and environments. Some of the bio-pesticides such as spinosads and avermectins produced by fungi, nuclear polyhedrosis virus (NPV), natural plant products, and *Bacillus thuringiensis* toxins are now being widely used as environment friendly products. However, many of these products are highly sensitive to the climatic factors. Increase in temperature and UV radiation, and a decreased in relative humidity may render many of these control tactics to be less effective. Relationships between insect pests and their natural enemies will change as a result of global warming, resulting in both increases and decreases in the status of individual pest species.

Changes in temperature will also alter the timing of diurnal activity patterns of different groups of insects, and changes in interspecific interactions could also alter the effectiveness of natural enemies for pest management (Hill and Dymock 1989; Sharma

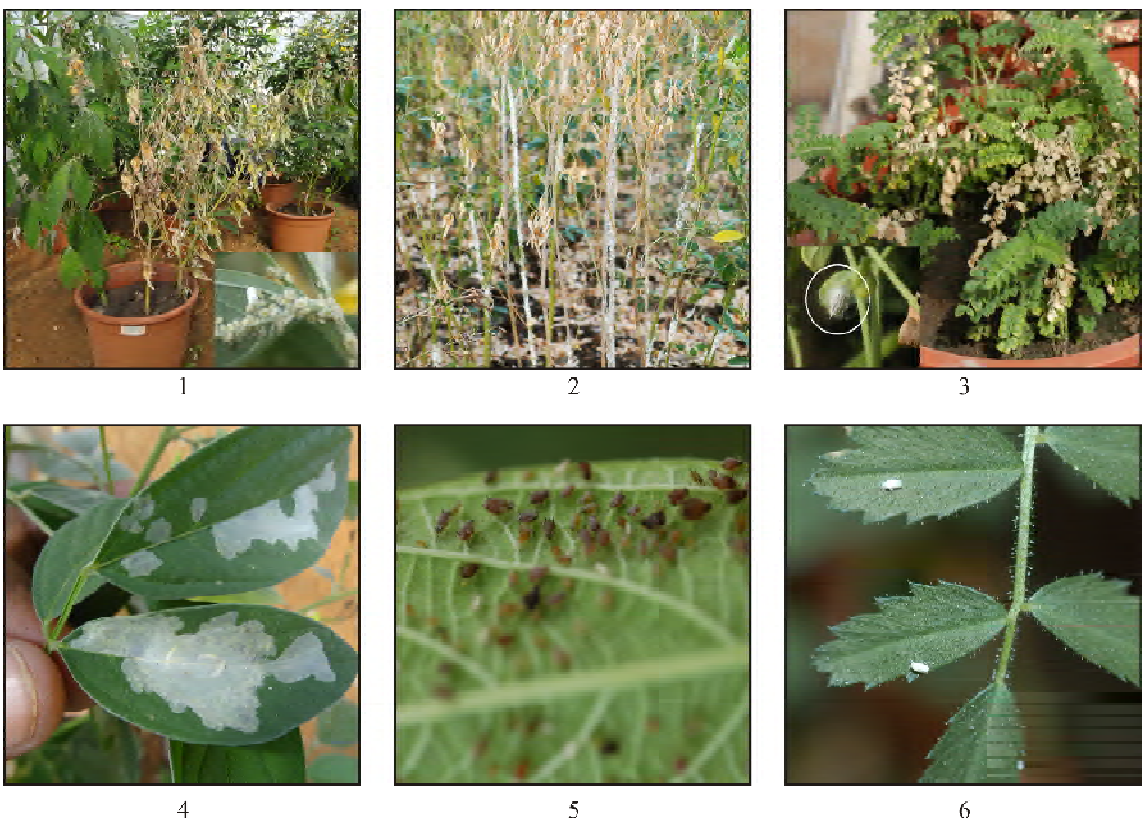

Plate 1-6: Emerging pest problems of pigeonpea and chickpea.
1) Mealy bug, *Coccidohystrix insolita* infestation in pigeonpea, 2) *Drepanococcus cajani* infestation in pigeonpea, 3) Chickpea plant damaged by mealy bug, *Ferrisia virgata*, 4) Leaf miner, *Porphyrosela neodoxa* infestation in pigeonpea, 5) *Aphis craccivora*, infestation in pigeonpea, 6) White fly, *Bemisia tabaci* infestation on chickpea in glasshouse.

2014). Quantifying the effect of climate change on the activity and effectiveness of natural enemies will be a major concern in future pest management programs. The majority of insects are benign to agro-ecosystems, and there is much evidence to suggest that this is due to population control through interspecific interactions among insect pests and their natural enemies (pathogens, parasites, and predators). Temperature not only affects the rate of insect development, but also has a profound effect on fecundity and sex ratio of parasitoids (Dhillon and Sharma 2009). The interactions between insect pests and their natural enemies need to be studied carefully to devise appropriate methods for using natural enemies in pest management. Therefore, there is a need for a greater understanding of the effect of climate change on the efficacy of natural enemies, host plant resistance, bio-pesticides and synthetic insecticides for pest management in order to develop appropriate strategies for mitigating the effects of climate change on crop production and food security.

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