Management of Legume Podborer, *Helicoverpa armigera* with Host Plant Resistance

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Abstract *Helicoverpa armigera* is the most important insect pest on wide variety of food, fibre, oilseed, fodder and horticultural crops commonly called as legume pod borer. Enormous amount of loss has been reported in deferent crops worldwide. Apart from being highly polyphagous, *H. armigera* is widely adapted to feeding on various plant parts. However, damage to the reproductive parts particularly to flowers and developing seeds results in direct loss. Hence, the level of Helicoverpa infestation during the flowering and fruiting phase is widely used as the basis for assessment of loss, and to quantify the genotypic resistance to this insect. Varieties of chickpea showing varying degrees of resistance to *H. armigera* have been developed at ICRISAT in India and some of these varieties have been used successfully by the farmers. Screening of more than 14800 germplasm accessions under natural infestations at ICRISAT has resulted in the identification of 21 donor showing antixenosis, antibiosis and tolerance mechanism of resistance, and these sources can be used in breeding programs. A high per cent of crude fibre and non reducing sugars and low per cent of starch have been found to be related with low incidence. Recent reports on significant variation in *Helicoverpa* gut proteinase inhibitors among chickpea genotypes escape insect attack or suffer less damage as compared to other genotypes because of phonological asynchrony. Deployment of *Helicoverpa*-resistant cultivars should be aimed at conservation of the natural enemies and minimizing the number of pesticide applications. Host plant resistance is compatible with other methods of insect control, exercises a constant and cumulative effect on insect populations over time and space, as no adverse effects on the environment, reduces the need to use pesticides, and involves no extra cost to the farmers.

Keywords Legume podborer; Management; Host plant resistance

Introduction

Legume podborer, *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) is the most important pest on wide variety of food, fibre, oilseed, fodder and horticultural crops. Its significance as a pest is based on the peculiarities of its biology such as high mobility, polyphagy, high reproductive rate and diapause. Its preference for flowering/fruiting parts of high value crops such as cotton, vegetables, corn and pulses confers a high socio-economic cost to its depredations under subsistence farming in the tropics and subtropics. Agronomic factors such as high yielding varieties, increased use of irrigation and fertilizers and large scale planting of alternate crop hosts have contributed to increased severity of this pest (Fitt, 1989). However, regional and local differences in host preference can give rise to differences in pest status on particular crops. Presently, *H. armigera* is a major pest of cotton in most of the cotton growing regions in Australia, Africa, India, Pakistan and China. Adult migration/immigration plays a major role in long term effectiveness of any control strategy aimed at suppressing more than one generation of this pest in a region. The precision in *Helicoverpa* control required most of these crops under high input conditions and the near absence of natural enemies in many crops and cropping systems, has led to a greater dependence on pesticides to minimize the extent of losses due to this pest.

Distribution and extent of losses

*H. armigera* is widely distributed in Asia, Africa, Oceania and the Europe (CIE, 1968; IIE, 1993). Its outbreaks/damage has also been reported from Hungary (Szenasi and Mesozros, 1997), Sicily (Pinto et al., 1997), Romania (Roman et al., 1996), Slovakia (Gomboc, 1999), Spain (Mejias et al., 1998), Sweden (Palmqvist, 1998),
Switzerland (Hachler et al., 1998) and the United Kingdom (Howard, 1998). Extensive damage by *Helicoverpa* has been reported on cotton, sunflower, chickpea, pigeonpea and vegetables. The damage to crops such as maize, sorghum and pulses can be quite severe in socio economic terms. Monetary losses result from the direct reduction in yield and the cost of monitoring and control, particularly the cost of insecticides. In Australia, the cost of monitoring and control has been estimated to be A$25 million. In India, total losses in both pulses cotton exceed $530 million per annum, and the insecticides applied for *Helicoverpa* control cost nearly $127.5 million on cotton and pulses. With this increased number of crop failures, greater insecticide use and development of resistance to insecticides (Mc Caffery et al., 1989), these figures may need to be revised upwards. The extent of losses in chickpea and pigeonpea has been estimated at over $645 million per annum in the semi arid tropics. In the tropics, total losses due to *Helicoverpa* on cotton, legumes, vegetables and cereals may exceed $2 billion and the cost insecticides used *H. armigera* may be over $500 million.

**Host range**

Information on host plants of *Helicoverpa* and *Heliothis* species complex has been summarized by various workers (Mathews, 1999). *H. armigera* is a major pest of cotton, pigeon pea, chickpea, sunflower, tomato, sorghum, pearl millet, groundnut, okra, field beans, soybean, Lucerne, *Phaseolus* spp, lentil, tobacco, potato, maize, linseed, fruits, forest trees and a range of vegetable crops. A wide range of wild plant species support larval development of which important species in India include *Hibiscus sp.*, *Acanthospermum* spp., *Datura* spp., *Gomphrena celosioides*; and in Africa comprise of *Amaranthus* spp. *Cleome amaranthus* (grain amaranthus), Gomphrena, Acaypha (copperleaf), Hyposcyamus has been reported in *Lagacea mollis* (Aherkar et al., 1999), *Canbis sativa* (Dippenaar et al., 1996), sowthistle (*Sonchus oleracea*) (Gu and Walter 1999), *Asparagus officinalis* (Kay and Hardy, 1999), Paulownia (Kumar and Ahmad, 1998), cape roosberry (*Physalis peruviana*) (Mehta et al., 1996), striga spp. (Onu et al., 1997), *Hyptis sauvelolons* and *Jatropa gossypiifloia* (Wilson, 1997) and *Lathyrus sativus* (Pophaly and Gupta, 1996).

**Nature of damage and economic thresholds**

In chickpea, the eggs are laid on leaves and young pods and the larvae initially feed on the young leaves and the larger larvae bore into the pods and consume the developing seeds. The larva also damages the fruiting bodies and leaves in several other crops.

**Host plant resistance to Legume pod borer, Helicoverpa armigera**

The development of crop cultivars with resistance to insects has a great potential for integrated pest management, particularly under subsistence farming conditions in the developing countries (Sharma et al., 1999). Many crop species possess some genetic variation, which can be exploited to produce varieties that are less susceptible to *H. armigera*. Breeding for resistance to insects has not been as rapidly accepted and developed, as is the case with disease resistant cultivars. This may be partly due to the relative ease with which insect control is achieved with use of insecticides. Another reason for slow progress in developing insect resistant cultivars has been the difficulties involved in ensuring adequate insect pressure for resistance screening. Insect rearing programmes are expensive, the technology development requires several years, and may not produce the behavioral or metabolic equivalent of an insect population in nature. However, with the development of insect resistance to insecticides, adverse effects of insecticides on natural enemies and public awareness of environmental pollution, there has been a renewed interest in the development of insect resistant cultivars. Establishment of international agricultural research centers and collection and evaluation of crop germplasm for insect resistance has given a renewed impetus to the identification and use of HPR as an integral component of pest management worldwide. Host plant resistance along with biological and cultural control is a central component of any pest management strategy.
under subsistence farming conditions.

Management of legume podborer
Assessment of economic threshold
A first step in developing an IPM approach is to establish the economic threshold of the target pest. This may be defined as the number of insects per unit area or per plant above which a significant economic loss in crop yield will occur, with reference to timing in the crop season and stage of the insect life cycle. Sharma (1985) reported 1 larva m⁻² row length as the economic threshold and injury level of *H. armigera* in chickpea.

Wightman *et al.* (1995) reported 9.7g per chickpea plant yield with no insect damage (multiplied by 130,000 plants ha⁻¹ to obtain a seed yield of 1.26 t ha⁻¹). As per statistical calculations based on experimental data, the authors reported that the presence of one larva (second or third instar) per plant reduced chickpea grain yield to 8.9 g per plant or 1.16 t ha⁻¹ (value Rs 7540 (when the market price in 1990 was Rs 6500 t⁻¹), a cost equivalent of Rs 650 which is close to the cost of one lannate application. From these estimates, the authors developed a first working hypothesis: “if a farmer finds more than one larva per plant (the action threshold) during the pod filling stage and applies an insecticide he should recover more than the cost from saved pods.

Integrated pest management
There are a range of potential options for control of *Helicoverpa* pod borer in chickpea. These are discussed below individually, prior to assessing how various options may best be combined into effective IPM packages.

Cultural manipulation of the crop and its environment
A number of cultural practices such as time of sowing, spacing, fertilizer application, deep ploughing, interculture and flooding have been reported to reduce the survival and damage by *Helicoverpa* spp. (Shanower *et al.*, 1998). Intercropping or strip-cropping with marigold, sunflower, linseed, mustard and coriander can minimize the extent of damage to the main crop. Strip-cropping also increases the efficiency of chemical control. Hand-picking of large sized larvae can also be practiced to reduce *Helicoverpa* damage. Habitat diversification to enhance pest control has been attempted in Australia. An area-wide population management strategy has been implemented in regions of Queensland and New South Wales to contain the size of the local *H. armigera* population, and chickpea trap crops have played an important role in this strategy. Chickpea trap crops are planted after the commercial crops to attract *H. armigera* as they emerge from winter diapause. The emergence from diapause typically occurs when commercial chickpea has senesced, and before summer crops (sorghum, cotton and mung bean) are attractive to moths (October to November). However, moths are diverted to weeds for oviposition (including wheat, *Triticum aestivum*) when they grow above the chickpea crop canopy (Sequeira *et al.*, 2001). Trap crops are managed in the same way as commercial crops, but destroyed by cultivation before larvae begin to pupate. The trap crops reduce the size of the local *H. armigera* population before it can infest summer crops and start to increase in size. As a result, the overall *H. armigera* pressure on summer crops is reduced, resulting in greater opportunity for the implementation of softer control options, reduced insecticide use and greater natural enemy activity.

Biological control
The importance of both biotic and abiotic factors on the seasonal abundance of *H. armigera* is poorly understood. The egg parasitoids, *Trichogramma* spp., are almost absent from chickpea ecosystem in India because of dense trichomes and their acidic exudates (Romeis *et al.*, 1999). The ichneumonid, *Campoletis chlorideae* (Uchida), is probably the most important larval parasitoid on *H. armigera* in chickpea in India. *Carcelia illota* (Curran), *Goniophthalmus halli* Mesnil and *Palexorista laxa* (Curran) have also been reported to parasitize up to 54% larvae
on chickpea (King, 1994), although Bhatnagar et al. (1983) recorded only 3% parasitism on chickpea. Predators such as Chrysopa spp., Chrysoperla spp., Nabis spp., Geocoris spp., Orius spp. and Polistes spp. are the most common in India. Provision of bird perches or planting of tall crops that serve as resting sites for insectivorous birds such as myna and drongo helps reduce the numbers of caterpillars.

The use of microbial pathogens including *H. armigera* nuclear polyhedrosis virus (HaNPV), entomopathogenic fungi, Bt, nematodes and natural plant products such as neem, custard apple and karanj kernel extracts have shown some potential to control *H. armigera* (Sharma, 2001). HaNPV has been reported to be a viable option to control *H. armigera* in chickpea (Cherry et al., 2000). Jaggery (0.5%), sucrose (0.5%), egg white (3%) and chickpea flour (1%) are effective in increasing the activity of HaNPV (Sonalkar et al., 1998). In Australia, the efficacy of HaNPV in chickpea has been increased by the addition of milk powder, and more recently the additive Aminofeed (Anonymous, 2005). Spraying Bt formulations in the evening results in better control than spraying at other times of the day (Mahapatro and Gupta, 1999). Entomopathogenic fungus, *Nomuraea rileyi* (106 spores per ml), results in 90~100% larval mortality, while *Beauveria bassiana* (2.68 × 107 spores per ml) resulted in 6% damage in chickpea compared to 16.3% damage in the untreated control plots (Saxena and Ahmad, 1997). In Australia, specific control of *H. armigera* and *H. punctigera* on chickpea is being achieved using the commercially available HaNPV, with an additive that increases the level of control. Bt formulations are also used as a spray to control Helicoverpa. Different isolates of HaNPV have been characterized for their variation in the genetic makeup (Kambrekar et al., 2005). Among the isolates screened, the HaNPV isolates collected from Coimbatore and Gulbarga have highest genetic variation. These isolates have been found very effective for the management of chickpea podborer both under laboratory and field conditions (Kambrekar et al., 2009). The virulent isolates were also effective on the podborer on other host crops like tomato (Kambrekar, 2012a), pigeonpea (Kambrekar, 2009) and sunflower (Kambrekar, 2012b) under field condition in India.

**Chemical control**

Management of *Helicoverpa* in India and Australia in chickpea and other high-value crops relies heavily on insecticides. There is substantial literature on the comparative efficacy of different insecticides against *Helicoverpa*. Endosulfan, cypermethrin, fenvalerate, thiodicarb, profenophos, spinosad and indoxacarb have been found to be effective for *H. armigera* control on chickpea in Australia (Murray et al., 2005a). Spray initiation at 50% flowering has been found to be most effective (Sharma, 2001). The appearance of insecticide resistance in *H. armigera*, but not in *H. punctigera* is considered to be related to the greater mobility of the latter species (Maelzer and Zalucki, 2000). However, *H. armigera* populations in the northern region are largely resistant to pyrethrroids, carbamates and organophosphates. Introduction of new chemistry, notably indoxacarb and spinosad, is being managed to minimize the develop-ment of resistance in *H. armigera* through a strategy that takes into account its use in all crops throughout the year (Murray et al., 2005a). Consequently, the use of indoxacarb in chickpea is limited to one application with a cut-off date for application to ensure one generation of *H. armigera* is not exposed to the product in any crop before the commencement of its use in summer crops (cotton and mung bean).

**Host plant resistance to chickpea podborer, *Helicoverpa armigera***

**Measurement of Resistance**

Apart from being highly polyphagus, *H. armigera* is widely adapted to feeding on various plant parts such as leaves, tender shoots, flower buds, flowers and seeds. Damage to vegetative parts result in indirect loss, and is generally compensated as a result of re growth in the affected plants. However, damage to the reproductive parts particularly to flowers and developing seeds results in direct loss. Hence, the level of *Helicoverpa* infestation during the flowering and fruiting phase is widely used as the basis for assessment of loss, and to quantify the
genotypic resistance to this insect. Numbers of fruiting bodies and the extent of damage is the final outcome of complex interaction involving *Helicoverpa* and its host plants.

A method of grading the test materials by using a 1 to 9 rating scale based on pod damage was suggested by Lateef and Reed (1995). Singh and Yadav (1999a) proposed three parameters (relative pest pressure index, relative intensity of damage index and relative productivity index) to screen chickpea genotypes against *H. armigera*. The relative resistance is computed by using the data on mean number of healthy and damaged pods per plant instead of percent pod damage. This method takes into account the number of pods per plant, which is an important character in selecting chickpea genotypes for high productivity (Singh and Singh 1998). Considering total number of pods per plant and number of damaged pods, it is the number of healthy pods per plant that contributes to the productivity of genotypes, e.g.: genotypes such as P256 and bahar of chickpea and pigeon pea, respectively has been found to be superior to others, by way of profuse podding and more number healthy pods per plant. But these genotypes, if considered on percentage pod damage basis would be inferior to those having less percentage pod damage, but too poor in podding. Genotypes with less number of pods also have a poor ability to compensate the loss due to insect damage. Since it is almost impossible to get a high level of resistance against *H. armigera* in any legume crops, search for genotypes with recovery resistance through their ability to have more pods and recover from initial damage would be more rewarding. Productivity of such genotypes may be further improved by mitigating the loss as a result of pod borer damage through the use of other control tactics.

**Direct measurements**

**Direct feeding injury**

Measurement of insect damage to plants are often more useful than measurements of insect growth or development. The plant damage and the resulting reduction in yield or quality are important while establishing the goals of a crop improvement program. At crop harvest, the test genotypes can be first evaluated visually for pod borer damage on a 1 to 9 scale, and then for the per cent damage to the fruiting bodies. At crop harvest count the total number of pods and the pods with pod borer larvae. Additional information on the susceptibility to other insects and diseases should also be recorded at an appropriate stage of the crop.

**Yield loss**

Measurements of yield reduction indicate direct insect feeding injury to plants. Measurements of quality of produce can also be used to measure the effect of insect damage. The test entries can also be planted under protected and unprotected conditions and per cent reduction in yield under unprotected conditions can be used as an index of relative susceptibility or resistance to *Helicoverpa armigera*. This method can also be used to measure the tolerance to *Helicoverpa* damage and stability of resistance under different insect densities. Different levels of insect infestation are created using different spray regimes or through artificial infestation. Less affected genotypes with low regression coefficients are selected in comparison with the susceptible genotypes with low regression coefficients are selected in comparison with the susceptible genotypes, which have high regression coefficients.

**Indirect measurements**

**Oviposition non preference**

Host plant resistance to *H. armigera* can also be measured in terms of relative preference for egg laying by the females e.g: moths of *Helicoverpa* lays 64 per cent less eggs on nectarless cottons (Lukefahr and Rhyne 1960). Oviposition non preference is also the major component of resistance to *H. armigera* females laid more eggs on ICPL 270, while ICPL 332, ICPL 84060 and LRG 30 were the less preferred varieties.
Larval abundance

Numbers of *H. armigera* larvae can be estimated by sampling at the plant site where the damage has taken place, and at the appropriate phenological plant stage and time. Shaking the plants, use of sampling nests, or actual counts are used to obtain an estimate of larval abundance. Number of larvae should be recorded in 3 to 5 plants at random in the centre of each plot at 10 to 15 days after flowering.

Feeding preference

Feeding preference of different instars can be measured using no choice test or multiple choice assays. Generally first or third instars are used to measure the feeding preference by the larvae (Green *et al.*, 2002).

Consumption and utilization of food

Several indices of consumption and utilization of food by the insects can also be used to determine the level of plant resistance to determine the level of plant resistance to insects (Waldbauer, 1968). Effect of plant resistance on insect per unit body weight per day (consumption index, CI) or leaf area consumed, larval growth rates (GR), appropriate digestibility (AD), and efficiency of conversion of digested food (ECD) into body matter.

Antibiosis

Antibiosis is expressed in terms of larval and pupal development periods, failure to pupate and reduced fecundity and egg viability. Antibiosis to insects in general is because of secondary plant substances, ex: oxalic acid in chick pea (Yoshida *et al.*, 1995) and flavonoids in pigeonpea (Sharma *et al.*, 2001). Adverse effects of the host plant on insects may also be because of poor nutritional quality of the host plant. Pupae of *H. armigera* from the larvae reared on ICC506 and ICCV7 weighed less than those reared on ICC37 (Cowgill and Lateef, 1996). Antibiosis effects are also expressed in terms of weight and size of insects, sex ratio and proportion of insects entering into diapauses (Jayaraj, 1982).

Tolerance

The levels of resistance to *H. armigera* in the germplasm accessories are low to moderate. This has necessitated the need of selecting genotypes with greater ability to tolerate or recover from the pod borer damage (Srivastava and Srivastava, 1989). The extent of damage during the podding stage can be reduced by selecting genotypes that flower and mature before and after the peak abundance of *H. armigera* and suffer low damage than those flowering during the periods of greatest insect abundance.

Identification and utilization of resistance

Shukla and Yadav (1998) and Srivastava and Sachan (1998) have discussed the advances made in host plant resistance to *H. armigera* in chickpea, pigeon pea, cotton and tomato in India. Varieties of chickpea showing varying degrees of resistance to *H. armigera* have been developed at ICRISAT in India and some of these varieties have been used successfully by the farmers (Sharma *et al.*, 1999). Borikar *et al.* (1982) screened 12 mutants, 3 strains and 3 varieties of chickpea for resistance to the pod borer. They observed that mutant Hira, Bronz leaf, N 59, 3-70, prabhat, chaffa, 3-1A-3, (Pinnate no.12), Himayatsagar, Alternifolia, Double pedicellate and chrysanthifolia yellow were less damaged compared to mutant green pod. Strain 2-52-2 and mutant pinnate showed the least damage and their grain yields were also high. Genotypes F 378 and C 235 (Srivastava *et al.*, 1975); H75-58, ICC 18 and Kanpur, Gondah and Mirzapur locals (Dias *et al.*, 1983); GL 645, Dulia 6-28, GCP Chaffa, P 1324-11, P1324-11, P6292 and selection 48 (Chhabra *et al.*, 1990); ICC 506EB, ICCV 7, ICC6663, ICC 10817, ICCL 86103, ICC4935, E 2793, ICCX 730041-8-B-BP, PDE 2 and PDE 5 (Lateef and Sachan, 1990); ICC506EB, ICCV 7, ICCV10, ICC 6663, Dulia, ICC 10667 and ICC 5264 (Lateef, 1985); Pusa 261 (Reddy *et al.*, 1996); BJ 256 (Kotikal *et al.*, 1996); C 235 (Ahmad and Kotwal, 1996; Deshmukh *et al.*, 1996a,b); ICC 506EB,
ICC6663, ICC10619, ICC10667 and ICCV7 (Singh, 1997); ICCV 7 (Singh et al., 1997); DHG 84-11, ICC 29, DHG 86-38, DHG 88-20, SG 90-55, KBG 1, IH 83-83, NP 37, DHG 87-54, GNG 669 and SG 89-11 (Singh and Yadav, 1999a); DHG 84-11, P 240, BG 79 and DHG 88-20 (Singh and Yadav, 1999b) and JG 74 (Das and Kataria, 1999) have been reported to be less susceptible to *H. armigera* in India. In Pakistan, Parvez et al. (1996) reported that line 1230 is resistant to this insect. Cultivar C44 gave the highest grain yield despite suffering from high pod borer damage, suggesting that it has got tolerance to *H. armigera* damage. In laboratory tests, significant differences have been observed in larval survival and pupal weight of *H. armigera* (Cowgill and Lateef, 1996) and of *H. punctigera* Hallgren on different accessories of chickpea. Although partial resistance to podborer has been identified in cultivated chickpea, efforts are also underway to look for resistance genes in wild species (Sharma et al., 2002). Accessions belonging to *Cicer bijugum*, *C. judaicum*, *C. reticulum* and *C. piinatifidum* have been found to be resistant to *H. armigera*. With the use of interspecific hybridization, it would be possible to transfer resistance genes from the wild relatives to cultivated chick pea.

Wild relatives of chickpea are an important source of resistance to leaf miner, *L. ciceri* and the bruchid, *C. chinensis* (Singh et al., 1997). Based on leaf feeding, larval survival and larval weights, accessions belonging to *C. bijugum* (ICC 17206, IG 70002, IG 70003, IG 70006, 70012, IG 70016 and IG 70016), *C. judaicum* (IG 69980, IG 70032 and IG 70033), *C. piinatifidum* (IG 69948) (Sharma et al., 2005) and *C. reticulatum* (IG 70020, IG 72940, IG 72948 and IG 72949, and IG 72964) (Sharma et al., 2005) showed resistance to *H. armigera*. With the use of interspecific hybridization, it would be possible to transfer resistance genes from the wild relatives to cultivated chickpea. Some of the wild relatives of chickpea may have different mechanisms of resistance than those in the cultivated types, which can be used in crop improvement to diversify the bases of resistance to this pest. Molecular marker-assisted selection (MAS) can be used to accelerate the introgression of desirable genes into improved cultivars (Sharma et al., 2002). A skeletal molecular map is already available from this mapping. Preliminary results on development of molecular markers for resistance to *H. armigera* have been reported in chickpea based on bulk segregant analysis with amplified fragment length poly-morphism (AFLP) analysis of F2 and F4 generations. Recombinant inbred lines (RILs) derived from ICCV × JG 62 cross have shown considerable variation for susceptibility to *H. armigera*. A susceptible *C. arietinum* variety (ICC [AU5] 3137) has been crossed with a *C. reticulatum* accession (IG 72934) resistant to *H. armigera*, and the F2 plants have been screened for resistance to *H. armigera*. Significant progress has been made over the last decade in introducing foreign genes into plants, providing opportunities to modify crops to increase yields, impart resistance to biotic and abiotic stresses and improve nutritional quality. Kaur et al. (1997) developed transgenic chickpea plants with *cry1Ac* gene. Efforts are underway at ICRISAT to develop transgenic plants of chickpea with *Bacillus thuringiensis* (Bt) and soybean trypsin inhibitor (SBTI) genes for resistance to *H. armigera*. Efficient tissue culture and transformation methods by using *Agrobacterium tumefaciens* have been standardized at ICRISAT.

Among the 16 genotypes of gram *Cicer arietinum* L. utilized for field assessment against gram pod borer in Pakistan to evaluate their genotypic differences, genotypes CM 2100/96 and CM-4068/97 were relatively resistant, while, lines No. 96051 and PBC-2000 susceptible against preference of the *H. armigera* in contrast to other genotypes (Sarwar, et al., 2011). Wakil et al. (2005) conducted field trails during the rabi season 2001-2002 in Rawalpindi (Pakistan) to investigate the twenty seven different genotypes of chickpea against *Helicoverpa armigera*. The parameters used for assessing these genotypes were the larval population plant-1 and the pod infestation. None of the genotypes showed complete resistance to the pest. The lowest pod infestation was recorded in CM-4068/97 (12.71%) and it ranged up to the maximum 38.83% (93127). Similarly, the larvae plant-1 war ranged from 1.27 (Paidar-91) to 5.40 (C-44).
Hussain (2009) screened twenty genotypes (14 lines and 6 released varieties) of chickpea in natural infestation condition in Bangladesh during the *rabi* season of 2003-04. The parameters used for evaluating these genotypes were relative pest pressure index (RPPI), relative intensity of damage index (RPPI), relative productivity index (RPI), and yield. None of the genotypes could exhibit complete resistance to pod borer, *Helicoverpa armigera* (Hubner). Considering overall performance ICCV-98939, ICCV-95138, ICCV-96020, ICCV-97004, BCX-91042-3, and BCX-91040-3 rated a more tolerant to pod borer attack in comparison to check (BARI Chola-5). Of them, ICCV-95138 was the best considering resistance and yield. ICC-4918 was the most susceptible. Nadeem *et al.* (2011) from Faisalabad evaluated the susceptibility of ten advanced Kabuli genotypes and a check variety to chickpea pod borer (CPB), *Helicoverpa armigera*. Genotypes CH 73/02, CH 76/02 and CC 121/00 were recorded as the most resistant against this insect pest. CH 72/02, CH 77/02 and CH 80/02 showed moderate resistance and CH 79/02, B 17/03, CH 65/02 and CH 60/02 the least resistance. CH 73/02 was highly resistant genotype showing the lowest pod damage (8.2%), decrease in damage (39.2%) and increase in grain yield (77.8%) over the check. The genotype, CH 60/02, was the least resistant showing 15.8% pod damage, 17.0% increased in damage and 53.3% decreased in yield over the check CM 2000. Results revealed that none of the genotype was completely resistant against this pest, however, the genotypes which showed the high and moderate resistance and better yield as compared to the check had the valuable resistance attributes against CPB as in Kabuli type chickpea. In Pakistan, Sarwar (2013) reported decreased pest population and peak yield in genotype CH-31/99.

In Sudan, genotypes Atmore and Flip03-139c were recorded higher resistant against pod borer than the Mattama, Hawata, Selwa, Wad Hamed, Jabel Marra, Flip03-127c and Flip04-9c, which were showed moderate resistant to pod borer. The cultivar Hawata gave the highest seed yield (1482 kg/ha) followed by Atmore (1276 kg/ha) and Shandi (1246 kg/ha) (Ali and Mohammad, 2014). None of the tested genotypes showed complete resistance against CPB after studying larval population, pod damage and grain yield parameters in Pakistan. Pod damage ranged from 10.9 to 22.8% among different genotypes. With respect to the check (CM 98) the minimum damage was –35.9% and maximum as 33.1%. Grain yield increase was recorded up to 100% over check in CH 16/02. Comparison of resistance among the genotypes against CPB showed that CM 188/01, CH 07/02, CH 20/02 and CH 84/02 possessed good resistance with increased grain yield over check. Intermediate resistance was evinced in CH 11/02, CH 15/02, CH 17/02 and CH 85/02. While genotypes CM 72/02, CM 246/02, CM 282/02 and CM 98 possessed minimum resistance against CPB. So genotype CH 16/02 showed over all better resistance against CPB, with low larval population, low pod damage and high grain yield (Shafiqe *et al.*, 2009).

Several factors probably contributed to the observed lack or increase in resistance of gram genotypes to pest. Thus, our results and those of Sharma *et al.*, (1999) suggest that the legume pod borer resistant reaction in legume is conditioned by a combination of factors such as oviposition, antibiosis and tolerance. They also reported that larvae reared on the resistant line had significantly lowered larval and pupal mass than those reared on the susceptible. This host selection process in *Helicoverpa* spp., was influenced by a large number of factors, including plant species, plant height and plant physiological stage (Jallow and Zalucki, 1996). An additional possible cause for the observed oviposition response was the chickpea foliar secretions containing high concentrations of malic acid (Rembold, 1981). The amount of foliar exudates and the concentration of malic acid depend on temperature and growth stage, and have been shown to increase during the reproductive stages of the plant (Koundal and Sinha, 1981). Whilst moths were drawn to chickpea in all growth stages, there was relatively less oviposition activity and damage in resistant cultivars that secrete high concentrations of malic acid (Reed *et al.*, 1987). Similar to our results, Shah and Shahzad (2005) monitored the seasonal changes in the population of *H. armigera*, data revealed that the pest population was low initially during 4 to 6 standard weeks, but increased from
7 standard week to onwards and declined again during 14 standard week. Our results correspond to all these earlier researchers. But, Mandal (2005) observed 5%-15% pod damage due to pod borers than our judgment from 13.24% to 38.00% damage due to variable pest incidence. Sharma et al. (2005) suggested that wild relatives of chickpea show high levels of antibiosis to *H. armigera* and can be used to introgress diverse resistance genes into cultivated chickpea to increase the levels and diversify the basis of resistance to this insect. So, genetically modified crop can provide substantial benefits to the farmers by providing enhanced protection against such pests. High to moderate resistance against CPB was observed in CH 09/02, B 8/03, B 8/02, CH 4/02, CH 31/02, CH 32/02 and CM 772/03; while CM 628/03, CH 52/02, CH 28/02 and CM 561/03 possessed minimum resistance. The genotype B 8/02 possessed the maximum comparative resistance with low larval population, less pod damage and high grain yield over check (Nadeem, et al., 2010).

**Physical and chemical mechanisms of plant resistance to *Helicoverpa armigera***

Three wild relatives of Chickpea (*Cicer bijugum, C. judaicum and C. pinnatifidum*) produce a variety of isoflavonoids in their roots (Stevenson and Veitch, 1998b), which are absent in the cultivated species (*C. arietinum*). These compounds are antifungal, and are known to be a defense mechanism against Fusarium wilt (*Fusarium oxysporum* f.sp. *ciceri*) (Stevenson and Veitch, 1998a). Another compounds amaackiain occurs in both the wild and cultivated species in the roots and leaves, and is a potent antifungal phytoalexin against both Fusarium wilt and botrytis grey mould (*Botrytis cinerea*) (Stevenson and Haware, 1999).

Recent studies have shown that these compounds may be useful targets to breed for resistance to *Helicoverpa* as they deter the pod borer from feeding (Simmonds and Stevenon, 2001). Four of these compounds have been shown to deter feeding by pod borer larvae at concentrations as low as 100ppm. Compound 4 and 5 retained their activity at 50 and 10ppm, indicating potent anti feeding activity (Table 1).

**Table 1** Effect of four compounds from chickpea roots on feeding behavior of sixth stadium larvae of *H. armigera* (Simmonds and Stevenson, 2001).

<table>
<thead>
<tr>
<th>Conc. Ppm</th>
<th>Judacian-7-O-glucoside</th>
<th>2-Methoxyjudacain</th>
<th>Judaicin</th>
<th>Maackiai</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Antifeedent index</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>35±4.2</td>
<td>32±8.1*</td>
<td>49±11.5*</td>
<td>53±5.6**</td>
</tr>
<tr>
<td>50</td>
<td>20±7.3</td>
<td>12±3.4</td>
<td>41±9.4</td>
<td>30±7.1*</td>
</tr>
<tr>
<td>10</td>
<td>5±6.7</td>
<td>10±5.9</td>
<td>15±5.5</td>
<td>33±6.6*</td>
</tr>
<tr>
<td>1</td>
<td>-3±8.4</td>
<td>3±4.11</td>
<td>5±3.6</td>
<td>21±6.1</td>
</tr>
</tbody>
</table>

*=P<0.05; **=P<0.01. Wilcoxon matched pair test

The compounds were tested in combination with each other, and with a common phenylpropanoid, chlorogenic acid. The combination containing 4 and 5 were found to be most active. Chlorogenic acid enhanced the antifeedent effect. Interestingly, larvae of *H. armigera* were only one of the four noctuvids to be deterred by all four isoflavonoids. *Spodoptera littoralis* was deterred by the compound four alone and *S. frugiferda* by compound 5 alone (Simmonds and Stevenon, 2001). Furthermore, when these isoflavonoids were incorporated into diets, they decreased the weight gain of young instars, and compound 4 and 5 were the most potent. Acid exudates from the leaf hairs contribute to the plant resistance to *H. armigera* in chickpea (Yoshida et al., 1995).

The isoflavonoids are either absent or at very low levels in the cultivated species. If we can manipulate the levels
of these compounds, it may possible to decrease the susceptibility of chickpea to damage by the pod borer. The wild relatives of chickpea also been evaluated for trypsin inhibitors (Patnakar et al., 1999). The diversity of protein inhibitors was greater in wild relatives than in the cultivated species, but *H. armigera* showed considerable adaptation to the protease inhibitors. This emphasizes the importance of having information about the insect response to the target compounds before we attempt to manipulate the crop via traditional breeding approaches via molecular approaches, which now looks increasingly possible. Regeneration of transformed chickpea has been achieved (Sharma et al., 2001), and the biosynthetic pathway for these isoflavanoids have been predicted (Stevenson and Veitch, 1998b). Thus, it is conceivable that since cultivated chickpea produces many of these precursors to the compounds described above, the genes for productions of isoflavanoids can be identified, and May transferred from the wild to the cultivated species.

**Sources of resistance to *H. armigera***

Progress in breeding for pod bore resistance depends on the availability of germplasm collections and, and identifications of resistance donors. Concerned effort to screen chickpea germplasm has led to the identification of many accessions exhibiting an impressive level of resistance to *H. armigera* (Banchhor et al. 2000; Gumber et al., 2000). Screening of more than 14800 germplasm accessions under natural infestations at ICRISAT has resulted in the identification of 21 donor showing antixenosis, antibiosis and tolerance mechanism of resistance, and these sources can be used in breeding programs (Table 2). Of them ICC 506, GL 645, PDE 2-3, PDE 7-3, ICC 10613, ICC 10619 and ICCL 79048 are most promising. Screening of wild relatives of *Cicer arietinum* has shown that the density of Helicoverpa larvae on *C. echinospermum, C. judanicum, C. pinnatifidium* and *C. reticulatum* were significantly lower than on the cultivated species (Kaur et al. 1999).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Donors</th>
</tr>
</thead>
</table>

During the course of evolution, plants acquired several defense mechanisms against insect pests to reduce the damage. The major Mechanisms are antixenosis, antibiosis, tolerance and escape (Painter, 1951). These Mechanisms are operational within the plant, through different component traits. Using specific assay to monitor the effects of particular physical and chemical characteristics on insect behavior and physiology, resistances
resistance has been differentiated in terms of antixenosis, antibiosis and tolerance. To date, more antibiosis than antixenosis or tolerance has been reported in legume crops (Clement et al., 1994). Many morphological characteristics which contribute to non preferences have been used to breed for resistance to *Helicoverpa* (Table 3).

Table 3 Characters associated to *Heliothis/ Helicoverpa armigera* in chick pea

<table>
<thead>
<tr>
<th>Crop</th>
<th>Mechanism</th>
<th>Characters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chick pea</td>
<td>Non-preference</td>
<td>Pod shape, pod wall thickness, foliage color and glabrousness</td>
</tr>
<tr>
<td></td>
<td>Antibiosis</td>
<td>Malic acid, oxalic acid, crude fibre, non-reducing sugars, low starch, cellulose, hemicelluloses, lignin in the pod wall, trypsin inhibitors and HG proteinase inhibitor.</td>
</tr>
<tr>
<td></td>
<td>Escape</td>
<td>Earliness and cold tolerance</td>
</tr>
</tbody>
</table>

Multiple types of resistance (antixenosis, antibiosis, tolerance and escape) are reported in Chickpea (Clement et al., 1994). Several morphological and phonological traits such as pod shape, pod wall thickness, foliage colour and crop duration seems to influence the *Helicoverpa* infestation in Chickpea (Ujagir and Khare, 1987). Pundir and Reddy (1989) reported a monogenetically controlled glabrous mutant from Chaffa cultivar, which could be a good differential host for pod borer because of its inability to produce malic acid and its effect on oviposition as the presence or absence of hairs on outer layers has bearing on oviposition by *Helicoverpa*. Srivastava and Srivastava (1990) studied antibiosis and observed large genotypic variation in larval survival, larval weight, pupal weight, egg variability, adult longevity and Howe’s growth index. Larval weight contributed maximally to the variation, followed by larval period, pupal period and pupal weight. A high per cent of crude fibre and non reducing sugars and low per cent of starch have been found to be related with low incidence of *Helicoverpa* in cultivar GL 645, while a high per cent of lignin, cellulose and hemicelluloses in the pod wall is thought to inhibit pod damage (Chhabra et al., 1990). Lateef (1985) suggested that amount of acid exudates on leaves as useful criteria for distinguishing resistant genotype from susceptible ones. Similarly, low amount of acidity in the leaf extract of genotypes ICC 14665 was associated with susceptibility to the *Helicoverpa* (Bhagwat et al., 1995). However, the resistant expressed by PDE 2-3, PDE 7-3 and ICC 506EB was attributed to factors other than acidity, while that of PDE 7-2 appeared due to high acidity. Recent reports on significant variation in *Helicoverpa* gut proteinase inhibitors among chickpea genotypes escape insect attack or suffer less damage as compared to other genotypes because of phonological asynchrony.

Among the factors responsible for *H. armigera* resistance in chickpea, the acid exudates (pH 1.3) with a high concentrations of malic acid secreted from the glandular hairs on the leaves, stems and pods has been recommended as a marker for resistance (Rembold, 1981). Chickpea exudates have malate and oxalate as the main components, and there were characteristics differences depending on the variety, diurnal cycles and growth stage. Varieties with the highest amount of malic acid had the highest resistance to *H. armigera* (Rembold, 1981).

**Advantages of HPR in Helicoverpa management**

Utilization of plant resistance as a control strategy has enormous practical relevance and additional emotional appeal (Davies, 1981). It is in this context that host plant resistance assumes a central role in our efforts to increase the production and productivity of crops. Plant resistance to insects is the backbone of any pest management system. Because:
1. It is specific to the target pest or a group of pests, and generally has no adverse effects on the non-target organisms;
2. Effects of plant resistance on insect population density are cumulative over successive generations of the target pest because of reduced survival, delayed development and reduced fecundity;
3. Most of the insect-resistant varieties express moderate high levels of resistance to the *Helicoverpa* throughout the crop growing season—in contrast the pesticides have to be applied repeatedly to achieve satisfactory control of pest populations;
4. HPR is compatible with other methods of pest control, and also improves the efficiency of other methods of pest management;
5. There are no harmful effects of HPR on non-target organisms, humans and environment;
6. It does not involve any costs to the farmer;
7. The farmers do not have to have any knowledge of application techniques.

Very high levels of resistance may neither be attainable nor required a variety capable of reducing the pest population by 50% in each generation can be useful in reducing the pest damage below economic threshold within a few generations (Painter, 1951). The cumulative and persistence effects of plant resistance are quite in contrast to the explosive effects of insecticides, where the insect population multiples at a much faster rate after the insecticide application because of absence of the absence of natural enemies.

**Future research needs**

Screening of germplasm collection and their wild relatives to identify lines with stable and diverse mechanisms of resistance.

1. An understanding of the mechanism that determine Helicoverpa movement/adaptation to different crop host and genotypes and an understanding of the mechanism and inheritance of resistance.
2. Gene pyramiding to increase the levels and diversify the bases of resistance to Helicoverpa in different crops.
3. Combine resistance to Helicoverpa with resistance to other important insect and diseases in a region.
4. Identification of molecular markers and quantitative trait loci (QTL) in different crops, to gain an understanding of the number of genes and nature of gene action for resistance to Helicoverpa.
5. Development of Helicoverpa resistant varieties through genetic transformation using genes with diverse mode of action.

**Conclusion**

Considerable progress has been made in developing techniques to screen for resistance to *H. armigera* under natural and artificial infestation. However, there is a need to establish insect rearing facilities at different research centers, and undertake multi locational testing of the identified sources and breeding materials to identify stable and diverse sources of resistance for use in crop improvement programs. Resistance to pod borer should be given as much emphasis as yield, to identify new varieties for cultivation by the farmers. Host plant resistance is compatible with other methods of insect control, exercises a constant and cumulative effect on insect populations over time and space, as no adverse effects on the environment, reduces the need to use pesticides, and involves no extra cost to the farmers. Host plant resistant to *Helicoverpa* can play an important role in pest management in different agro-ecosystems, and lead to sustainable crop production and environment conservation.

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