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Insect pest management in food legumes: The future strategies

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Abstract

Food legumes such as chickpea, pigeonpea, cowpea, field pea, lentil, faba bean, blackgram, greengram, grasspea, and *Phaseolus* beans play an important role in the daily diets of people worldwide. These crops are damaged by a large number of insect pests, of which pod borers, *Helicoverpa armigera* and *H. punctigera*; spotted pod borer, *Maruca vitrata*; spiny pod borer, *Etiella zinckenella*; pod fly, *Melanagromyza obtusa*; leaf miner, *Liriomyza cicerina*; stem fly, *Ophiomyia phaseoli*; pea and bean weevil, *Sitona* spp.; aphids, *Aphis craccivora*, *Aphis fabae*, and *Acyrthosiphon pisum*; white fly, *Bemisia tabaci*; defoliators, *Spodoptera litura*, *S. exigua*, and *Amsacta* spp.; leafhoppers, *Empoasca* spp., thrips, *Megaleurothrips dorsalis*, and *Caliothrips indicus*; blister beetles, *Mylabris* spp.; and the bruchids, *Collasobruchus chinensis* and *Bruchus pisorum* cause extensive losses worldwide. Because of development of resistance to insecticides in several insect species, there is a

need to integrate different control tactics. Sources of resistance to insects in grain legumes have been identified, but these have not been used effectively in crop improvement. There is a need to place greater emphasis on utilization of wild relatives of crops with different resistance mechanisms, genetic engineering of plants for insect resistance, and identification of molecular markers associated with resistance to insect pests. Cultural manipulation of the crop and its environment, population monitoring and pest forecasting, manipulation of the crop environment to encourage the activity of natural enemies, use of natural plant products and bio-pesticides alone or in combination with synthetic pesticides, deployment of insect-resistant varieties derived through conventional breeding, wide hybridization, or genetic engineering, and rational use of selective chemicals can be exploited for pest management in food legumes.

Introduction

Food legumes such as chickpea (*Cicer arietinum* L.), pigeonpea [*Cajanus cajan* (L.) Millsp.], cowpea (*Vigna unguiculata* Walp.), field pea (*Pisum sativum* L.), lentil (*Lens culinaris* Medik.), greengram [*Vigna radiata* (L.) Wilczek], blackgram [*Vigna mungo* (L.) Hepper], French bean (*Phaseolus vulgaris* L.), faba bean (*Vicia faba* L.), and grasspea (*Lathyrus sativus* L.) are the principal source of dietary protein among vegetarians, and are an integral part of daily diet in several forms worldwide. Grain legumes are cultivated on 23 million hectares, accounting for over 18% of the total arable area, but only 8% of the total grain production. There is a large disparity between yields of cereals and legumes. The global pulse production in 2004 was over 60.45 million tonnes over an area of 71.44 million ha, and average productivity of 846 kg ha^{-1} (FAO, 2004). In India, the total pulse production in 2004 was 14.94 million tonnes on 23.44 million ha, with an average productivity of 637 kg ha^{-1}. Worldwide, chickpea and pigeonpea are the two major food legumes, cultivated on 10.38 and 4.57 million ha, respectively. The total production being 8.57 and 3.29 million tonnes, with an average productivity of 826 and 720 kg ha^{-1}, respectively. In addition to being a source of dietary proteins and income to resource poor farmers, food legumes play an important role in sustainable crop production. They are an important component of cropping systems to maintain soil health because of their ability to fix atmospheric nitrogen, extract water and nutrients from the deeper layers of the soil, and add organic matter into the soil through leaf drop. However, food legumes are mainly grown under rainfed conditions and the productivity levels are low, mainly because of severe losses due to insect pests and diseases.

Insect Pest Problems in Grain Legumes

Grain legumes, being a rich source of proteins, are damaged by a large number of insect pests, both under field conditions and in storage (Clement *et al.*, 2000) (Table 1). Amongst the many insect pests damaging food legumes, the pod borers, *Helicoverpa armigera* (Hübner) and *H. punctigera* (Wallengreen) are the most devastating pests of chickpea and pigeonpea in Asia, Africa, and Australia. They also damage other food legumes to varying degrees in these regions (Sharma, 2001). The spotted pod borer, *Maruca vitrata* (Geyer), is

Table 1. Important insect pests of food legumes

Common name	Scientific name	Distribution	Chick-pea	Pigeon-pea	Cow-pea	Field pea	Lentil	*Phaseolus* beans	Green gram	Black gram
Pod borers	*Helicoverpa armigera* (Hub.)									
	Helicoverpa punctigera	As, Af, Aus	xxx	xxx	x	xx	x	xx	x	x
Walllengren										
Spotted pod borer	*Maruca vitrata* (Geyer)	As, Af, Aus, Am	-	xxx	xxx	x	-	xxx	xx	xx
Spiny pod borer	*Etiella zinckenella* Treit.	As, Af, Am	-	x	-	xxx	xx	-	-	-
Pod fly	*Melanagomyza obtusa* Malloch	As, Af	-	xxx	-	-	-	-	-	-
Leaf miner	*Liriomyza cicerina* (Rondani)	As, Naf	xx	-	-	-	-	-	-	-
Pod sucking bugs	*Clavigralla gibbosa* Spin.									
	Clavigralla tomentosicollis (Stal.)	As, Af, Aus, Eu, Am	-	xx	xx	x	x	x	x	x
Pea and bean weevil	*Sitona* spp.	As, Naf, Am	-	-	-	xx	xx	xx	-	-
Blister beetles	*Mylabris* spp.	As, Af	-	xx	x	-	-	xx	xx	xx
Aphids	*Aphis craccivora* Koch.									
	Acyrthosiphon pisum Harris									
	Aphis fabae (Scop.)	Ww	x	x	xx	xx	xx	xx	xx	xx
Whitefly	*Bemisia tabaci* Genn.	Ww	-	-	-	-	-	xx	xx	xx
Defoliators	*Spodoptera litura* F.,	As, Am*	-	x	x	x	x	x	x	x
		*S. exigua** Hub., *Amsacta* spp., *Spilosoma obliqua* Walk.								
Leaf hoppers	*Empoasca kerri* Pruthi	As	-	x	x	x	x	xx	xx	xx
Stem flies	*Ophiomyia phaseoli* Tryon.	As, Af, Aus, Eu	-	-	-	xxx	-	xx	xx	xx
Thrips	*Caliothrips indicus* Bag.									
	Megaleurothrips distalis Karny	Ww	-	x	x	x	-	xx	xx	xx
Pea weevil	*Bruchus pisorum* L.	Ww	-	-	-	xx	-	-	-	-
Bruchids	*Collasobruchus chinensis* L.	Ww	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx

xxx = Highly important. xx = Moderately important. x = Occasional pest. As = Asia, Naf = North Africa. Af – Africa, Am = Americas, Aus = Australia, Eu = Europe, and Ww = Worldwide distribution.

a major pest of cowpea and pigeonpea, but also damages other food legumes, except chickpea and lentil (Sharma *et al.*, 1999). The pod fly, *Melanagromyza obtusa* Malloch, and pod wasp, *Tanaostigmodes cajaninae* La Sale, causes extensive damage to pigeonpea in India. The leaf miner, *Liriomyza cicerina* (Rondani) is an important pest of chickpea in West Asia and North Africa (Weigand *et al.*, 1994), and North India (Naresh and Malik, 1986). The spiny pod borer, *Etiella zinckenella* Triet, is a major pest of pigeonpea, field pea, and lentil. The aphid, *Aphis craccivora* Koch, infests all the food legumes, but is a major pest of cowpea, field pea, faba bean, and *Phaseolus* beans, while *Aphis fabae* (Scop.) is a major pest of faba bean and *Phaseolus* beans. The pea aphid, *Acyrthocyphon pisum* Harris, is a major pest of field pea worldwide. The cotton whitefly, *Bemisia tabaci* Genn., infests all crops, except chickpea, but is an important pest of *Phaseolus* spp., blackgram, and greengram. The defoliators [*Spodoptera litura* (Fab.) in Asia and *S. exigua* Hubner in Asia and North America), are occasional pests. The Bihar hairy caterpillar, *Spilosoma obliqua* Walk, is a major pest of greengram and blackgram in North India, while the red hairy caterpillars, *Amsacta* spp., damage the rainy season pulses in South central India. Leafhoppers, *Empoasca* spp., infest most of the food legumes, but cause economic damage in blackgram, greengram, and *Phaseolus* beans. Pod sucking bugs (*Clavigralla tomentosicollis* Stal., *C. gibbosa* Spin., *Nezara viridula* L. and *Bagrada hilaris* Burm.), are occasional pests but extensive damage has been recorded in cowpea by *C. tomentosicollis* in Africa, and *C. gibbosa* in pigeonpea in India. The redlegged earth mite, *Halotydeus destructor* Tucker, is a seedling pest of field peas in Australia (Thackray *et al.*, 1997; Ridsdill-Smith, 1997; Liu *et al.* 2001). The pea and bean weevil, *Sitona lineatus* L., is a pest of field pea in the U.S. Pacific Northwest, while *S. crinitus* Herbst. is a pest of pea and other legumes in Asia. The thrips *Megaleurothrips dorsalis* Karny and *Caliothrips indicus* Bag., can cause extensive flower damage in food legumes. The bruchids, *Collasobruchus chinensis* L., and *C. maculatus* Fab., cause extensive losses in storage in all the food legumes worldwide. The pea weevil, *Bruchus pisorum* L., is a major pest of field pea in most production areas (Clement *et al.*, 1999).

Extent of Losses

Insect pests in India cause an average of 30% loss in pulses valued at $815 million, which at times can be 100% (Dhaliwal and Arora, 1994). In Africa, insect pests can be responsible for extensive damage (up to 100%) in cowpea, the major food legume on this continent (Singh and Jackai, 1985), while in the U.S., the avoidable losses have been estimated at 40 to 45% (Javaid *et al.*, 2005). In Pakistan, nearly 10% of the chickpea grain is lost due to bruchids in storage (Aslam, 2004), and at times, there may be complete loss of grain in storage. *Helicoverpa armigera* – the single largest yield reducing factor in food legumes, causes an estimated loss of US$317 million in pigeonpea, and $328 million in chickpea (ICRISAT, 1992). Globally, it causes an estimated loss of over $2 billion annually, despite over $1 billion worth of insecticides

the estimates of yield losses vary from 5 to 10% in the temperate regions and 50 to 100% in the tropics (van Emden *et al.*, 1988). The avoidable losses in food legumes at current production levels of 60.45 million tonnes would be nearly 18.14 million tonnes (at an average loss of 30%), valued at nearly US$ 10 billion.

Pest Management Strategies

Monitoring and Sampling of Pest Populations

Monitoring of pest populations is the key to determine if a threshold has been exceeded and control measures are required (Clement *et al.*, 2000). Monitoring of pest populations through light or pheromone traps is practiced for *H. armigera* in Asia (Trivedi *et al.*, 2005), and *Harmigera* and *H. punctigera* in Australia (Loss *et al.*, 1998). Sampling based on direct counts or insect damage has been used for *H. armigera* in chickpea and pigeonpea (Wightman *et al.*, 1995), *H. punctigera* in chickpea (Loss *et al.*, 1998), *M. vitrata* in cowpea (Jackai, 1990; Oghiakhe *et al.*, 1992), *L. cicerina* in chickpea (Weigand and Pimbert, 1993), *B. pisorum* in field pea (Smith and Hepworth, 1992), pea and bean weevil, *S. lineatus* in faba bean (Ward and Morse, 1995) and field pea (O'Keeffe *et al.*, 1991)., *S. crinitis* Herbst. in lentil (Kaya and Hincal, 1987), *A. fabae* in faba bean (Ward and Morse, 1995), and *A. pisum* in field pea (Soroka and Mackay, 1990). Sweepnet method has been used for *Lygus hespersus* Knight (Schotzko and O'Keeffe, 1989), *H. punctigera* (Loss *et al.*, 1998), *B. pisorum* (Smith and Hepworth, 1992), and *A. pisum* (Maiteki and Lamb, 1985). Soil sampling has been used to assess egg density of *Sitona* spp. (Nielsen, 1990). Plant shaking has been employed to dislodge the larvae of *H. punctigera* on different crops in Australia (McIntyre and Titmarsh, 1989; Loss *et al.*, 1998).

Economic Thresholds

Economic or action thresholds have often been used to time insecticide sprays or other interventions aimed at pest suppression. Economic thresholds have been determined for *H. armigera* on pigeonpea (one egg or larva per plant or 2% pod damage) (Goyal *et al.*, 1990; Meenakshisundaram and Gujar, 1998) and chickpea (one larva per meter row) (Wightman *et al.*, 1995; Khurana, 1997). Economic thresholds have been established for *H. punctigera* on chickpea in Australia (Loss *et al.*, 1998), and *B. pisorum* on field pea (Horne and Bailey, 1991). Additionally, economic thresholds based on sweepnet sampling have been established for *A. pisum* (Maiteki and Lamb, 1985, Loss *et al.*, 1998). Small producers in many developing countries have limited resources, and are unwilling to spend money on insect control until damage is visible or large larvae are seen on the crop. At low population levels, this may be a good policy. However, when infestations are heavy, by the time spraying commences, the damage has already been done. Therefore, it is important to monitor adults, eggs and early larval growth stages, as well as plant damage, to undertake appropriate and timely control measures.

Cultural Manipulation of the Crop and its Environment

Timely planting: Early and timely planting of crops can help avoid periods of peak abundance of *H. armigera* in chickpea and pigeonpea in India (Weigand *et al.*, 1994; Dahiya *et al.*, 1999). However, early planting of chickpea is ineffective in southern India because of moderate temperatures during the crop-growing season, which sustain high *H. armigera* populations. High planting densities aggravate *H. armigera* infestation in chickpea (Reed *et al.*, 1987). Use of short-duration cultivars has often been used to avoid pest damage, but

short-duration pigeonpea suffers greater damage by the spotted pod borer, *M. vitrata* in southern India. Increased infestations of *Sitona* sp. have been observed in late sown crops in Syria. Winter-sown chickpea suffers less damage by the leaf miner than the spring-sown one (Weigand *et al.*, 1994). Early harvesting of peas reduces the losses due to *B. pisorum* in Australia (Baker, 1990a,b).

Tillage: Deep ploughing of fields before planting and after crop harvest can expose insect pupae in soil to biotic and abiotic mortality factors. For example, ploughing destroys the over-wintering population of *H. armigera* and other noctuids (Rummel and Neece, 1989; Fitt and Cotter, 2005). During interculture operations, birds such as common myna (*Acridotheres tristis*), egrets (*Egretta* spp.), bulbul (*Bulbacus ibis*) and drongos (*Dicrurus adsimilis*) follow the ploughshare to eat insects that are exposed.

Application of Fertilizers and Plant Growth Regulators: Heavy fertilizer application results in luxuriant plant growth, and as a result the crop may suffer greater damage. Sprays of super phosphate (1%) have been found to result in a significant reduction in oviposition by *H. armigera* females in China (Sharma, 2001). Early termination of flowering and fruiting also reduces the population carryover from one season to another, and also reduces the number of generations (Fitt, 1989).

Intercropping: Careful selection of a cropping system can minimize the losses due to insects. Intercropping chickpea with mustard, linseed, or safflower (Das, 1998), and pigeonpea with cowpea (Hegde and Lingappa, 1996) and sorghum (Mohammed and Rao, 1999) result in reduced damage by *H. armigera*. Intercropping can also be used as a means of encouraging the activity of natural enemies (Bhatnagar *et al.*, 1983). Planting non-host crops before the planting of susceptible legume crops such as pea and faba bean reduces the damage by the redlegged earth mite (Ridsdill-Smith, 1997).

Trap Crops: Trap crops and diversionary hosts have been widely used to reduce the damage by *H. armigera*, but there is little data to demonstrate their effectiveness under field conditions (Pearson, 1958; Fitt, 1989). Marigold, sesame, sunflower, and carrots can be used as trap crops for *H. armigera*. In Australia, chickpea and pigeonpea are used as trap crops in cotton growing regions to reduce damage by *H. armigera*. Use of plant kairomones to lure *B. pisorum* (Clement *et al.*, 2000) and *H. armigera* (Rembold and Rembold *et al.*, 1990) into traps or toxin baits has also been suggested.

Mechanical Control: Hand picking of the larvae, nipping the plant terminals with eggs, and shaking plants to dislodge the larvae (particularly in pigeonpea) has been suggested to reduce *H. armigera* damage (Ranga Rao *et al.*, 2005). Ploughing destroys pupae of *H. armigera* in the soil (Fitt and Cotter, 2005). Crops that serve as perches for insectivorous birds (e.g., sunflower in chickpea) or provision of bird perches increases the predation by insectivorous birds such as myna and drongo. Egg masses and larvae of *S. litura* and *Amsacta* spp. can also be hand picked and destroyed.

Flooding: Flooding with water affects *H. armigera and H. punctigera* pupal survival and moth emergence. Irrigation or flooding of cotton fields at the time of pupation reduces

pupal survival and leads to decreased population densities in the following generation or season (Murray and Zalucki, 1990). However, chickpea grown under rainfed conditions is not amenable to flooding due to water scarcity.

Host Plant Resistance

Conventional Breeding Approaches: Grain legume germplasm with resistance to insect pests has been identified, but the sources of resistance have not been used extensively in breeding programs (Clement et al., 1994, Sharma and Ortiz, 2002). Insect resistance-breeding programs are underway for a few crop pests only. Entomologists and plant breeders have experienced difficulties in screening and selecting for resistance to target pests, in part, because of the lack of uniform insect infestations across locations and seasons. In addition, it is difficult to rear and multiply some of the insect species on synthetic diets for artificial infestation. Cultivars with resistance to insect pests have been identified in pigeonpea, chickpea, cowpea, blackgram, greengram, and field pea (Table 2). However, the levels of resistance are low to moderate. Cultivars with multiple-resistance to insects and diseases will be in greater demand in future because of the concerns associated with chemical control and environmental pollution. There is a need to break the linkage between insect resistance and susceptibility to diseases, e.g., in chickpea and pigeonpea, *H. armigera*-resistant cultivars are susceptible to wilt (Sharma *et al.*, 2005a). In Australia, narrow-leafed lupins, *Lupinus angustifolius*, with resistance to aphids (cvs Kalya and Tanjil) are being used in the field, which have greatly reduced the need to apply insecticides (Edwards *et al.*, 2003).

Screening of entire germplasm collections of chickpea and pigeonpea (over 15,000 accessions for each crop) has led to identification of a few accessions with moderate levels of resistance to *H. armigera* (Lateef, 1985; Lateef and Pimbert, 1990). However, lack of precision in evaluating thousands of accessions for resistance to the target pests probably resulted in missing many potentially good sources of resistance. In lentil, genotypic differences for susceptibility to aphid (*A. craccivora*), pod borer (*E. zinkenella*), and seed weevil have been observed, but no attempts have been made to breed for resistance to insects (Erskine *et al.*, 1994). Sources of resistance to chickpea leaf miner have been identified (Singh and Weigand, 1996), and used successfully in the breeding program at ICARDA. Several F_6 lines with good level of resistance to leaf miner and good agronomic characters have been developed and will soon be shared with the National Programs in North Africa and West Asia (Malhotra, R., ICARDA, personal communication).

Exploitation of Wild Relatives as Sources of Resistance to Insect Pests: High levels of insect resistance have been reported in the wild relatives of several crops (Clement, 2002; Sharma *et al.*, 2001, 2005b,c). Wild relatives of pigeonpea such as *Cajanus scarabaeoides, C. platycarpus*, *C. acutifolius,* and *C. sericeus* have high levels of resistance to *H. armigera* (Sharma *et al.*, 2001, 2005a). In chickpea, accessions belonging to *Cicer bijugum*, *C. judaicum*, *C. cuneatum*, and *C. microphyllum* have also been identified with high levels of resistance to *H. armigera* (Sharma *et al.*, 2002b, 2005b,c). Wild relatives of chickpea are also important sources of resistance to the leaf miner, *L. cicerina* and the bruchid, *C. chinensis*

Table 2. Identification and utilization of host plant resistance to insect pests in food legumes (information largely on insect pests in India)

Crop	Genotypes	Reference
Pigeonpea	Pod borer, *Helicoverpa armigera*	Lateef and Pimbert (1990),
	ICPL 332*, PPE 45-2, ICPL 84060, BDN 2, ICPL 4, Bori, T 21, ICP 7035 and ICPL 88039	Kalariya *et al.* (1998), Parsai (1996)
	Pod fly *Melanagromyza obtusa*	
	ICP 10531-E1, ICP 7941E1, ICP 7946-E1 and ICP 7176-5	Lateef and Pimbert (1990)
Chickpea	Pod borer, *Helicoverpa armigera*	
	ICC 506, ICCV 7*, ICCV 10*, Dulia*, C 235*, JG 79*, BG 256*, Vijay and Vishal	Lateef and Sachan (1990),
		Bhagwat *et al.* (1995), Reddy *et al.*
	Leaf miner, *Liriomyza cicerina*	(1996), Das and Kataria (1999),
		Deshmukh *et al.* (1996 a,b)
		ILC 380, ILC 5901 and ILC 7738
		Singh and Weigand (1996).
Blackgram	Pod borer, *Helicoverpa armigera*	Lal (1987)
	Kalai*, 338-3, Krishna*, and Co 3*, 4* and 5*	
	Jassid, *Empoasca kerri*	
	Sinkheda 1*, Krishna*, H 70-3 and UPB 1*	
	Stem fly, *Ophiomyia phaseoli*	
	Killikullam*, 338/3, P 58, Co 4* and Co 5*	
Greengram	Pod borer, *Maruca testulalis*	
		J1, LM 11, P 526 and P 336.
Lakshminarayana and Misra (1992)		
	ML 337, ML 5, MH 85-61 and ML 325.	
	Stem fly, *Ophiomyia centrosematis* Co 3	
Field pea	Pod borer, *Etiella zinkenella*	Lal (1987)
	EC 33860, Bonville*, T 6113*, PS 410, 2S 21 and 172M	
	Leaf miner, *Chromatomyia horticola*	
	P 402, PS 41-6, T 6113, PS 40, KMPR 9, P 402 and P 200	
Cowpea	Pod borer, *Maruca vitrata*	Singh (1978), Lal (1987)
	TVu 946, VITA 4, VITA 5, Ife Brown, and Banswara*.	
	Jassid, *Empoasca kerri*	
	TVu 123, TVu 662, JG 10-72, C 152 and 3-779 (1159).	
	Aphid, *Aphis craccivora*	
	P 1473, P 1476 and MS 9369	

*Released for cultivation in India.

(Singh and Ocampo, 1997). Accessions belonging to *Vigna vaxillata* (TVNu 72 and TVNu 73), a wild relative of cowpea, have shown high levels of resistance to *M. vitrata* (Jackai and Oghiakhe, 1989). In pea, the accessions belonging to the wild relative, *Pisum fulvum* are not preferred for egg-laying by the bruchid, *B. pisorum* (Ali *et al.*, 1994). *Pisum* accessions have been screened in the field for susceptibility to pea weevil (Hardie *et al.*, 1995), and variation for resistance has been observed in *P. fulvum* (Clement *et al.*, 2002). The challenge now is to develop effective systems for introgression of resistance genes from the wild relatives into high-yielding cultivars. Marker-assisted breeding offers the potential to break deleterious linkage drag associated with unwanted genes from the wild relatives, and to effectively pyramid genes for multiple resistance to insect pests and diseases with desirable agronomic traits (Sharma *et al.*, 2002a).

Transgenics: While several transgenic crops with insecticidal genes have been introduced in the temperate regions, very little has been done to use this technology for improving crop productivity in the harsh environments of the tropics, where the need for increasing food production is most urgent (Sharma *et al.*, 2004). Progress in developing transgenic plants of food legumes has been reviewed by Popelka *et al.* (2004). A tissue culture and regeneration protocol has been developed for chickpea and pigeonpea, which has been found to be useful for genetic transformation of these crops (Thu *et al.*, 2003; Jayanand *et al.*, 2003; Dayal *et al.*, 2003). Chickpea cultivars ICCV 1 and ICCV 6, transformed with *cry1Ac* gene, have been found to inhibit the development of and feeding by *H. armigera* (Kar *et al.*, 1997). Transgenic pigeonpea plants with *cry1Ab* and soybean trypsin inhibitor *(SBTI)* genes have been developed at ICRISAT, and are being tested against *H. armigera* (Gopalaswamy *et al.*, 2003). Transgenic chickpea expressing cowpea trypsin inhibitor (Thu *et al.*, 2003), and a-amylase inhibitor (Shade *et al.*, 1994; Schroeder *et al.*, 1995; Sarmah *et al.*, 2004) with resistance to bruchids has also been developed. Research in Australia has led to the development of transgenic pea for resistance to pea weevil through the expression of á-amylase inhibitor (Morton *et al.*, 2000; Sousa-Majer *et al.*, 2004), but this technology is not available to pea breeders in Australia, the USA, and other countries because of the concerns associated with the use of transgenic crops as food.

Molecular Markers: The use of DNA markers for indirect selection offers the greatest potential gains for quantitative traits with low heritability, as these are the most difficult characters to work with through conventional phenotypic selection. The quality of a marker-assisted selection program can only be as good as the quality of the phenotypic data on which the development of that marker was based. Therefore, it is essential to use large mapping populations characterized across seasons and locations, and using well-defined phenotyping protocols. Progress in marker-aided selection for resistance to insect pests is quite limited. Mapping the complex traits such as resistance to pod borer, *H. armigera* in chickpea is just beginning (Lawlor *et al.*, 1998). A mapping population derived from a cross between a wilt-resistant *kabuli* variety (ICCV 2) and a wilt-susceptible *desi* variety (JG 62) has been used to develop the first intraspecific genetic linkage map of chickpea (Cho *et al.*, 2002). This population has also been evaluated for resistance to *H. armigera*, and the data

analysis is in progress. Another mapping population (Vijay x ICC 506EB) has also been developed and evaluated for resistance to *H. armigera*. In pigeonpea, a mapping population involving *C. cajan* x *C. scarabaeoides* is under development at ICRISAT (Upadhyaya, H.D., personal communication).

A cross between an aphid (*A. craccivora*) resistant cultivated cowpea (IT 84S-2246-4) and an aphid susceptible wild cowpea (NI 963) has been evaluated for aphid resistance and RFLP (restricted fragment length polymorphism) marker segregation (Myers *et al.*, 1996). The RFLP marker *bg4D9b* was linked to the aphid resistance gene (*Rac1*), and several flanking markers in the same linkage group (linkage group 1) have also been identified. Tar'an *et al.* (2002) developed the genetic linkage map of common bean. Murray *et al.* (2000) detected genetic loci for resistance to potato leafhopper, *Empoasca fabae* (Harris). In greengram, *TC1966* bruchid resistance gene has been mapped using RFLP markers (Young *et al.*, 1992). Resistance was mapped to a single locus on linkage group VIII (approximately 3.6 cM from the nearest RFLP marker). Based on RFLP analysis, a progeny was also identified in the F_2 population that retained the bruchid resistance gene within a tightly linked double crossover. This progeny might be useful in developing mungbean lines resistant to bruchids, and free of linkage drag. Yang *et al.* (1998) used RFLP marker-assisted selection in backcross breeding for introgression of the bruchid resistance gene in greengram, while Kaga and Ishimoto (1998) studied genetic localization of a bruchid resistance gene and its relationship to insecticidal cyclopeptide alkaloids, the vignatic acids in greengram. The random amplified polymorphic DNA (RAPD) markers have also been used to identify markers linked to the bruchid resistance in mungbean (Villareal *et al.*, 1998). The gene was 25 cM from *pM151a*. When *pM151a* and *pM151b* were considered as alleles of the same locus, the bruchid resistance gene was located 11.9 cM from the nearest RAPD marker *Q04* sub 900, and 5.6 cM from *pM151*. Progress has also been made in locating molecular markers for resistance to pea weevil in crosses between field pea (*P. sativum*) and the wild species (*P. fulvum*) (Byrne *et al.*, 2002).

Biological Control

The importance of both biotic and abiotic factors on seasonal abundance of insect pests is poorly understood. Early stage mortality is invariably the most severe, although its causes and extent vary greatly, and comparable data sets are too few to identify the factors responsible for population regulation across regions. There is voluminous information on parasitism, and to a lesser extent on predation of insect pests of different food legumes. The egg parasitoids, *Trichogramma* spp. and *Telenomus* spp. destroy large numbers of eggs of *H. armigera* and *H. punctigera,* but their activity levels are too low in chickpea and pigeonpea because of trichome exudates. The ichneumonid, *Campoletis chlorideae* Uchida is probably the most important larval parasitoid of *H. armigera* on chickpea and pigeonpea in India (Pawar *et al.,* 1986). Tachinids parasitize late-instar *H. armigera* larvae, but result in little reduction in larval density. In India, *Carcelia illota* (Curran), and to a lesser extent, *Goniophthalmus halli* Mesnil, and *Palexorista laxa* (Curran) parasitize up to 22% of *H. armigera* larvae on pigeonpea (Bhatnagar *et al.,* 1983), and up to 54% larvae in chickpea

(A.B.S. King, unpublished). There are a few reliable estimates of pre-pupal and pupal mortality of *H. armigera,* which may be as high as 80% (King, 1994). Six species of parasitoids have been recorded from field-collected *Helicoverpa* pupae (Fitt, 1989). Population of *L. cicerina* parasitoids builds up late in the season in West Asia (Weigand *et al.*, 1994). Potential biocontrol agents for *B. pisorum* have also been documented (Annis and O'Keeffe, 1987; Baker, 1990 a,b).

The most common predators of insect pests of food legumes are *Chrysopa* spp., *Chrysoperla* spp., *Nabis* spp., *Geocoris* spp., *Orius* spp., *Polistes* spp., and species belonging to Pentatomidae, Reduviidae, Coccinellidae, Carabidae, Formicidae and Araneida (Zalucki *et al.,* 1986; van den Berg *et al.,* 1988; Romeis and Shanower, 1996; Sharma, 2001). Some predators have been used in augmentative release studies, notably *Chrysoperla carnea* (Stephens) (Ridgeway *et al.,* 1977). Although effective in large numbers, the high cost of large-scale production precludes their economic use in biological control in food legumes (King *et al.*, 1986).

There is considerable information on entomophagous pathogens against *H. armigera* and *H. punctigera,* although to date, these tactics have not provided a viable alternative to insecticides. Spraying *Bacillus thuringiensis* (*Bt*) formulations in the evening results in better control than spraying at other times of the day (Mahapatro and Gupta, 1999). The entomopathogenic fungus *Nomuraea rileyi* (@ 10^6 spores per ml) resulted in 90 to 100% larval mortality, while *Beauveria bassiana* (@ 2.68 x 10^7 spores per ml) resulted in 6% damage on chickpea compared to 16.3% damage in untreated plots (Saxena and Ahmad, 1997). A significant and negative correlation has been observed between insect mortality due to NPV and foliar pH, phenols, tannins, and protein binding capacity (Ramarethinam *et al.*, 1998). In Australia, a commercially available NPV has been tested extensively, with an additive that increases the level of control. Neem and custard apple extracts, and neem and karanj (*Pongamia*) oil based formulations have also been recommended for the management of *H. armigera* (Ranga Rao *et al.*, 2005). Much remains to be done to develop stable formulations of biopesticides for them to be effective for the control of *H. armigera* and other insect pests on food legumes. Vegetable oils, neem oil and karanj oil provide effective protection against bruchid damage in pulses (Reddy *et al.*, 1994). Karanj oil, and leaf and seed extracts act as oviposition deterrents (Kumar and Singh, 2002).

Chemical Control

Management of insect pests in food legumes relies heavily on insecticides, often to the exclusion of other methods. Control measures directed at adults, eggs, and neonate larvae are most effective in minimizing *H. armigera* damage. Spray decisions based on egg counts could destroy both invading adults and eggs, and leave a residue to kill future eggs and neonate larvae. Young larvae are difficult to find as they burrow into the flowers where they become less accessible to contact insecticides. Spray initiation at 50% flowering has been found to be most effective (Singh and Gupta, 1997). As a result of heavy selection pressure, *H. armigera* has developed resistance to the major classes of insecticides. *Helicoverpa*

armigera populations have shown resistance to endosulfan, thiodicarb, and methomyl in Australia (Daly *et al.*, 1988; Gunning *et al.*, 1996); cypermethrin, endosulfan, quinalphos, monocrotophos, carbaryl, chlorpyrifos, phosalone, fenvalerate, and deltamethrin in India (Armes *et al.*, 1996; Kranthi *et al.*, 2002); cypermethrin, cyfluthrin, deltamethrin, bifenthrin, lambda-cyhalothrin, monocrotophos, ethion, chlorpyriphos, and profenfos in Pakistan (Ahmad *et al.*, 1997a,b); and fenvalerate in Thailand (Burikam *et al.*, 1998). Insecticide resistance management strategies have been developed in several countries to prevent the development of resistance or to contain it. All strategies rely on a strict temporal restriction in the use of pyrethroids and their alteration with other insecticide groups to minimize selection for resistance (Sawicki and Denholm, 1987). Considerable information has also been generated on chemical control of *B. pisorum* in pea (Micheal *et al.*, 1990), *S. lineatus* and *A. fabae* in faba bean (Ward and Morse, 1995), and aphid vectors in lupins (Bwye *et al.*, 1997).

Integrated Pest Management Modules

Monitoring the movement of insect pests, particularly *Helicoverpa* , could provide an early warning of its invasion in an area or crop. Timely forecasts give farmers sufficient time to make appropriate pest management decisions. Traps (light, pheromone, suction, or wind traps) can be used to monitor pest populations to develop pest-forecasting models. For example, pheromone and light trap catches of moths have been used to provide forecasts of *H. armigera* infestations in Asia and Australia. However, the relationship between trap catches and subsequent egg or larval populations is variable (Srivastava *et al.*, 1992). The relationship between egg, larval, and moth catches in traps is closest when moth densities are low at the beginning of the season. Catches in pheromone-baited traps exhibit a negative, but non-significant correlation with temperature, wind speed, sunshine, and rainfall; and a significant and positive correlation with maximum relative humidity (Dhawan and Simwat, 1996). Moth catches in pheromone traps are influenced by stage of crop, location of the trap, and the weather conditions. The use of phenological or time parameters in predictive models is also important to improve the performance of pest forecasting models.

Das and Kataria (1999) developed a prediction model for *H. armigera* on chickpea based on temperature, relative humidity, and rainfall. In Australia, *H. punctigera* breeds on native plants in non-cropping inland areas and migrates to cropping areas in the spring (Zalucki *et al.*, 1994). The size of the second generation of this species is linked to first generation, winter rainfall (positive effect, i.e., increased *Helicoverpa* infestation) and spring rainfall (negative effect, i.e., decreased infestation), which accounted for 96% of the variation in second generation (Maelzer *et al.*, 1996; Maelzer and Zalucki, 1999). Pheromone traps have also been used to provide local forecasts of *Helicoverpa* infestations in grain legumes in Australia (Walden, 1995). The model, HEAPS, incorporates modules based on adult movement, oviposition, development, survival, and host phenology (Dillon and Fitt, 1990; Hamilton and Fitt, 1990). Decision support systems for managing insect pests in cotton in Australia have been updated as SIRATAC and CottonLOGIC (Hearn and Bange, 2002), and the guidelines are also available on the internet webpage at http://cotton.pi.csiro.au/

Publicat/Pest/ (Fitt and Cotter, 2005). The optimal time and application frequency to control the larval progeny of a wholly immigrant population were most sensitive to the time and duration of immigration, flowering time, moth age at immigration, and development time of young larvae. Like the other models, this model is also specific to the local ecology of the pest and the particular cropping system. Information on population dynamics and modeling has also been generated for pea seed weevil (Smith and Ward, 1995), aphids on lupin (Thackray, 1996), and pea aphid on field pea (Bommarco and Ekbom, 1995; Clement *et al.*, 2000).

In view of the need to exploit the existing spectra of natural enemies to reduce excessive dependence on chemical control, various IPM programs have been developed for pest management in different crops. These vary from judicious use of insecticides based on economic thresholds and regular scouting to sophisticated population models to assess the need, optimum timing, and selection of insecticides. A major constraint to the development of IPM has been the need to deal with a complex of pests, where control needs may be irreconcilable. Formulations based on *Bt* and HaNPV are effective for controlling *H. armigera* on chickpea and pigeonpea (Singh *et al.*, 1999). Alternate sprays of endosulfan and monocrotophos, and endosulfan and NPV are effective for the control of pod borer (Kumawat and Jheeba, 1999). The relative efficacy of quinalphos and HaNPV varies across seasons and the genotypes (Cowgill and Bhagwat, 1996). Insecticide mixtures Spark (deltamethrin 1% + triazophos 35%) and Polytron C (cypermethrin 4% + profenfos 40%) are also effective against *Helicoverpa* , with or without the addition of *Bt* (Pal *et al.*, 1996; Shaw *et al.*, 1999). Methomyl and chlorpyriphos sprays are superior to HaNPV (Giraddi *et al.*, 1997). Finally, pest-resistant cultivars derived through conventional breeding and genetic engineering, and deployment of insect-resistant genes from the closely related wild relatives of crops need to be developed for IPM in food legumes (Table 3) (Popelka *et al.*, 2004; Sharma *et al.*, 2004, 2005a).

There is considerable information on the insect pests that damage food legumes in different countries, although the factors that influence the population build up and population dynamics of many insect species is not sufficiently understood. There is a need to gain a thorough understanding of the factors that lead to heavy losses in food legumes. Cultivars with resistance to insect pests will play a pivotal role in pest management in food legumes, but only if breeding programs utilize identified sources of resistance. Resistance genes from closely related wild relatives of grain legumes should also be utilized wherever possible. Genetically engineered plants with different insecticidal genes can also play a role in IPM. Molecular marker-assisted selection has the potential to pyramid resistance genes and other desirable traits to magnify the value of host plant resistance in food legume IPM. Moreover, cultural practices that reduce the intensity of insect pests are another important element of pest control. Cropping systems that encourage the activity and abundance of natural enemies should be popularized among the farmers. Insecticides provide quick and effective pest control in food legumes. However, where insecticide resistance has developed as in case of *Helicoverpa*, a more integrative strategy may be needed. Neem seed kernel extract, *Bt*, and

Table 3. Integrated pest management in food legumes: The prospects

Crop	Cultural practices	Biological control	Chemical control: SC	Chemical control: BP	HPR	Host plant resistance: Wide hybridization	Host plant resistance: Transgenics	Host plant resistance: MAS
Pigeonpea	Sw, Till, Int, Mech, Tr, and Fld	*Goniophthalmus* *Campoletis* *Carcelia*	Ca, Sp Oc, Op Mi	NPV, Ma Bb, Np	ICPL 332, ICP 187-1, T 21, and and ICPL 84060	*Cajanus scarabaeoides*, *C. sericeus*, and *C. acutifolius*	*cry1Ac* *cry2a* *SBTI* *CpTi*	X
Chickpea	Sw, Till, Int, Tr, Per, and Fld	*Campoletis* *Palexorista*	Oc, Sp Ca, Mi	NPV, Np	ICC 506, and ICCV 10	*Cicer reticulatum*, *C. bijugum*, and *C. judaicum*	*cry1Ac* *cry2a*	XXX
Cowpea	Sw, Int, Tr, and Per	*Antrocephalus*, *Palexorista zygobothria*, coccinellids, chrysopids, syrphids	Sp, Oc Op	Ma, Bb Np	VITA 4, VITA 5, Ife Brown, and Banswara	*Vigna vexillata*	*cry1Ac* *cry2a* *SBTI* *CpTi*	XX
Phaseolus beans	Sw, Till, and Int	*Cotesia*, *Telenomus*, coccinellids, chrysopids, syrphids	Sp, Oc Op	Ma, Bb Np	Krishna, Co4, ML 325 and UPB 1	-	*cry1Ac* *cry2a* *SBTI* *CpTi*	XX
Pea	Sw, Till, Int, Tr, and Fld	*Bracon*, *Solenotus*, *Pediobius*	Sp, Op	Ma, Bb Np	Bonville, T 6113, PS 410, 2S 21 and 172M	*Pisum fulvum*	*cry1Ac* *cry2a* *SBTI* *CpTi*	XXX

Sw = Sowing time. Till = Tillage. Int = Intercropping. Tr = Trap cropping. Per = Bird perches. Fld = Flooding. SC = Synthetic chemicals. BP = Biopesticides. HPR = Host plant resistance. MAS = Marker assisted selection. Sp = Synthetic pyrethroids. Op = Organophosphates. Ca = Carbamates. Mi = Molting inhibitors with ovicidal action. Oc = Organochlorine compounds. NPV = Nuclear polyhedrosis virus. Ma = *Metarrhizium anisopliae.* Bb = *Beauveria bassiana.* Np = Natural pesticides. XXX = Highly important. XX = Moderately important. X = Low importance.

HaNPV have been recommended in many cases, but limitations on timely availability, quality control, and economic feasibility limit their use in pest management on a regular basis. However, biopesticides applied in combination with synthetic insecticides or in rotation can be quite effective for pest management on different crops. Release of natural enemies for biological control has been successful in some situations. The integrated strategy has to be developed for each region to suit the farming practices of the growers in that region.

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