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CHAPTER - 10

Pest Management in Grain Legumes: Potential and Limitations

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10.1 Introduction

Grain legumes such as chickpea, pigeonpea, cowpea, field pea , lentil, , and Phaseolus beans are the principal source of dietary protein among vegetarians, and are an integral part of daily diet in several forms worldwide. They are an important component of cropping systems to maintain soil fertility because of their ability to fix atmospheric nitrogen, extract water and nutrients from the deeper layers of the soil as compared to cereals, and add organic matter into the soil through leaf drop. However, grain legumes are mainly grown under rainfed conditions and the productivity levels are quite low mainly because of severe losses due to insect pests and diseases. Average grain yield of pulses (0.86 t/ha) is only about one-fourth the average yields of cereals (3.54 t/ha). Production and productivity of grain legumes is constrained by several biotic and abiotic factors, and suffer an average of 31.9 to 69.6% loss in crop productivity due to insects, diseases, drought, weeds, and soil fertility. Pod borers (*Helicoverpa* and *Maruca*), Fusarium wilts, viral diseases, Ascochyta blight and Botrytis gray mold (Chen *et al.*, 2011).

10.2 Insect Pest Problems in Grain Legumes

Grain legumes are damaged by a large number of insect species under field conditions and in storage (Sharma *et al.*, 2010) (Table 10.1). Pod borers, *Helicoverpa armigera* (Hubner) and *H. punctigera* (Wallengren) are the most devastating pests of chickpea and pigeonpea in Asia, Africa, and Australia. The spotted pod borer, *Maruca vitrata* (Geyer), is a major pest of cowpea and pigeonpea (Sharma *et al.*, 1999). The pod fly, *Melanagromyza obtusa* Malloch 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). The spiny pod borer, *Etiella zinckenella* Triet. is a major pest of pigeonpea, field pea, and lentil.

Table 10.1 : Important insect pests of grain legumes.

Common name	Scientific name	Distribution	Chick-pea	Pigeon-pea	Cow-pea	Field pea	Lentil	*Phaseolus* beans	*Faba bean*
Pod borers	*Helicoverpa armigera* (Hub.) *Helicoverpa punctigera* Walllengren	As, Af, Aus	xxx	xxx	x	xx	x	xx	
Spotted pod borer	*Maruca vitrata* (Geyer)	As, Af, Aus, Am	-	xxx	xxx	x	-	xxx	
Spiny pod borer	*Etiella zinckenella* Treit.	As, Af, Am	-	x	-	xxx	xx	-	
Pod fly	*Melana gomyza obtusa* Malloch	As, Aus	-	xxx	-	-	-	-	
Leaf miner	*Liriomyza cicerina* (Rondani)	As, Naf	xx	-	-	-	-	-	
Stem fly	*Ophiomyia phaseoli* Tryon		-	-	-	xx	-	xx	
Pod suck-ing bugs	*Clavigralla gibbosa* Spin. *Clavigrala tomentosicollis* (Stal.)	As, Af, Aus, Eu, Am	-	xx	xx	x	x	x	x
Pea and bean weevil	*Sitona* spp.	As, Naf, Am	-	-	-	xx	xx	xx	xx

Blister beetles	*Mylabris* spp.	As, Af	-	xx	x	-	-	xx	-
Aphids	*Aphis craccivora* Koch. *Acyrthocyp-hum pisum* Harris *Aphis fabae* (Scop.)	Ww	x	x	xx	xx	x xx	xx	xx xx
Whitefly	*Bemisia tabaci* Genn.	Ww	-	-	-	-	-	xx	
Defoliators	*Spodoptera litura* F., *S. exigua** Hub., *Amsacta* spp., *Spilosoma obliqua* Walk.	As, Am*	-	x	x	x	x	x	
Leaf hoppers	*Empoasca kerri* Pruthi	As	-	x	x	x	x	xx	
Stem flies	*Ophiomyia phaseoli* Tryon.	As, Af, Aus, Eu	-	-	-	xxx	-	xx	
Thrips	*Caliothrips indicus* Bag. *Megaleuro-thrips usitatus* (Bag.)	Ww	-	x	x	x	-	xx	
Pea weevil	*Bruchus pisorum* L.	Ww	-	-	-	xx	-	-	
Bruchids	*Calloso bruchus chinensis* L.	Ww	xxx	xxx	xxx	xxx	xxx	xxx	xx

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

The aphid, *Aphis craccivora* Koch 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, *Acyrthosiphon pisum* Harris is a major pest of field pea and lentil. The cotton whitefly, *Bemisia tabaci* Genn. is an important pest of *Phaseolus* spp., black gram, and green gram. The defoliators [*Spodoptera litura* (Fab.) in Asia and *S. exigua* Hubner in Asia and North America, are occasional pests. Leafhoppers, *Empoasca* spp. 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 pea and bean weevil, *Sitona lineatus* L. is a pest of field pea in the U.S. Pacific Northwest, and faba bean in North Africa and West Asia, while *S. crinitus* Herbst. is a pest of pea, lentil and other legumes in Asia and North Africa. The thrips, *Megaleurothrips* usitatus (Bagnall) in Asia, and *M. sjostedti* Trybom in Africa, and *Caliothrips indicus* Bag. cause extensive flower damage in food legumes. The bruchids, *Callosobruchus chinensis* L. and *C. maculatus* Fab. cause extensive losses in storage. The pea weevil, *Bruchus pisorum* L. is a major pest of field pea in most production areas (Clement *et al.*, 1999; Lal, 1987).

Losses due to insect pests vary across crops and regions (Table 10.2), and cause an average of 30% loss in India, which is valued at $815 million, which at times could be 100% (Dhaliwal and Arora, 1994). In Africa, insect pests can be responsible for extensive damage (up to 100%) in cowpea. (Singh and Jackai, 1985), while in the U.S., the avoidable losses have been estimated at 40 to 45% (Javaid *et al.*, 2005). *Helicoverpa armigera* – the single largest yield reducing factor in food legumes, causes an estimated loss of over $ 2 billion annually, despite over $ 1 billion worth of insecticides used to control this pest (Sharma, 2005). In general, 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 tons (at an average loss of 30%), valued at nearly US$ 10 billion (Sharma *et al.*, 2010).

Table 10.2 : Yield losses (%) due to major insect pests in grain legumes in different regions.

Crop/constraint	**SA**	**ESA**	**WCA**	**WANA**	**LA**
Chickpea					
Insect pests:	**26.0**	**20.0**	-	**20.0**	-
*Helicoverpa**	18.0	15.0		12.0	
Leaf miner/aphids/cut worm	8.0	5.0		8.0	
Common bean					
Insect pests:	**25.0**	**20.0**	**20.0**	-	**28.0**
Bean fly/Apion	15.0	15.0	10.0	16.0	
Leaf hoppers/aphids	10.0	5.0	10.0	-	12.0
Cowpea					
Insect pests:	**25.0**	**25.0**	**22.0**	-	**26.0**
Flower thrips	5.0	5.0	8.0		7.0
Pod bugs	5.0	5.0	5.0		6.0
*Maruca**	10.0	10.0	4.0		9.0
Aphids	5.0	5.0	5.0		4.0
Faba bean					
Insect pests: Aphids	**15.0**	**15.0**	-	**5.0**	-

Lentil					
Insect pests:	**12.0**	**15.0**		**20.0**	
Sitona weevil	5.0	10.0		15.0	
Aphids	7.0	5.0	-	5.0	-
Pigeonpea					
Insect pests:	**40.0**	**42.0**	-	-	-
*Helicoverpa/Maruca**	20.0	20.0			
Pod fly	13.0	15.0			
Pod sucking bugs	7.0	7.0			
Soybean					
Insect pests:	**20.0**	**15.0**	**25.0**	-	**20.0**
Pod sucking bugs	5.0	5.0	5.0		5.0
Bean fly*	8.0	5.0	8.0		10.0
Leaf defoliators	7.0	5.0	12.0		5.0

SA = South Asia, ESA = East and southern Africa, WCA = West and central Africa, WANA = West Asia and North Africa, and LA = Latin America.

*Have the potential to cause complete loss during outbreaks, which are quite frequent in the tropics.

Bruchids cause an average of 10 – 15% loss across crops/regions in storage.

Based on published information on percentage yield loss in different regions in various crops. Yield loss due to insect pests in a region has been computed as a percentage of total yield loss.

10.2.1 Pest management in grain legumes

10.2.1.1 Cultural practices

Early and timely planting is useful to avoid heavy insect damage in grain legumes. Early planting of chickpea in winter suffers less damage by the leaf miner, *L. cicerina* as compared to the spring-sown crop. The second generation of the leaf miner coincides with young, spring-sown chickpea plants (in contrast to the winter-sown crop); and hence, the higher level of infestation in spring-sown chickpea (Weigand *et al.* 1994; El Bouhssini *et al.* 2008a*).* However, early planting of chickpea suffers more damage in southern India because of high populations of *H. armigera*. Planting times might become more uncertain under climate change, *e.g.* during the 2009 rainy season, delay in the onset of monsoons by 30 days resulted in delayed plantings of pigeonpea, which was damaged by *H. armigera,* while heavy rains during August resulted in greater insect damage in soybean. Use of short-duration cultivars has often been used to avoid pest damage, but short-duration pigeonpea suffers greater damage by *M. vitrata* in southern India. Increased infestations of *Sitona crinitus* have been observed in late sown lentil in Syria. Early harvesting of peas reduces the losses due to *B. pisorum* in Australia (Baker, 1990 a,b).

Deep ploughing of fields before planting and after crop harvest destroys the over-wintering population of *H. armigera* and soil inhabiting pests (Rummel and Neece, 1989; Fitt and Cotter, 2005). Irrigation or flooding of fields at the time of pupation reduces survival of *H. armigera*, and leads to decreased population densities in the following generation or season (Murray and Zalucki, 1990). During intercultural operations, birds such as common Myna (*Acridotheres tristis* L.), egrets (*Egretta* spp.), and drongos (*Dicrurus adsimilis* L.) follow the ploughshare to feed on insects that are exposed to the soil surface. Heavy fertilizer application results in luxuriant plant growth resulting in greater damage due to insect pests. Early termination of flowering and fruiting reduces the population carryover from one season to another, and also reduces the number of generations of *H. armigera* (Fitt, 1989), and has been used as one of the components for the management of this pest on cotton.

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). Trap crops and diversionary hosts have also been widely used to reduce the damage by *H. armigera* (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 to reduce damage by *H. armigera*. Use of plant kairomones to lure *B. pisorum* (Clement *et al.*, 2000) and *H. armigera* (Rembold and Tober, 1985; Rembold *et al.*, 1990) into traps or toxin baits has also been suggested. Hand picking of the larvae, nipping the plant terminals with eggs, and shaking the plants to dislodge the larvae (particularly in pigeonpea) has been suggested to reduce *H. armigera* damage (Ranga Rao *et al.*, 2005). Bird perches can also be used to increase the predation by insectivorous birds such as myna and drongo. Egg masses and larvae of *S. litura* and *Amsacta* spp. can also be picked up by hand and destroyed. Although many crop management practices help to reduce pest incidence and yield loss in grain legumes, most of these practices need to be used in conjunction with other components of pest management in an integrated pest management program. The cultural practices have the advantage that they are compatible with all the other components of pest management in different combinations.

10.2.1.2 Host plant resistance

Sources of resistance to insect pests have been identified, but have not been used extensively in breeding programs (Bhagwat *et al.*, 1995; Malhotra *et al.*, 2007; Sharma *et al.*, 2010). Because of the lack of uniform insect infestations across seasons and difficulty in rearing some insect species, it has not been possible to make a rapid progress in developing insect resistant cultivars. Cultivars with resistance to insect pests have been identified in pigeonpea, chickpea, cowpea, black gram, green gram, and field pea (Singh, 1978; Parasai, 1996; Kalaria *et al.*, 1998; Das and Kataria, 1999; Jakai, 1990). However, the levels of resistance to some of the pests such as *H. armigera* are low to moderate. However, even low levels of resistance could be quite effective when deployed in combination with synthetic pesticides (Sharma and Pampapathy, 2004; El Bouhssini *et al.*, 2008 b). Cultivars with multiple-resistance to insects and dis-eases 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; Deshmukh *et al.*, 1996a,b).

Screening of over 15,000 accessions of chickpea and pigeonpea has led to identification of a few accessions with moderate levels of resistance to *H. armigera* (Lateef, 1985; Lateef and Pimbert, 1990, Lateef and Sachan, 1990). In lentil, genotypic differences for susceptibility to aphid (*A. craccivora*), pod borer (*E. zinkenella*), and seed weevil have been observed (Erskine *et al.*, 1994). Eight accessions of wild lentils have been identified to be resistant to *S. crinitus* (d"10 % nodule damage compared to >56% damage in accessions belonging to the cultivated species) (El Bouhssini *et al.*, 2008b). This was the first report on resistance against *Sitona* weevil in lentil. The resistant accession ILWL 245 belongs to the species *L. culinaris* Medikus subsp. *orientalis*, which is the progenitor of the cultivated lentil, and has crossability with the cultivated lentils. Sources of resistance to chickpea leaf miner have been identified, and used successfully in the breeding programs (Singh and Weigand, 1996; El Bouhssini *et al.*, 2008b; Malhotra *et al.*, 2007).

Development of cultivars with stable resistance to insect pests would provide an effective approach in pest management. However, it is not possible to develop cultivars with high levels of resistance to several key pest of grain legumes, particularly the pod borers as the levels of resistance in the cultivated germplasm are low to moderate. Therefore, efforts have to be made to introgress resistance genes either through wide hybridization from the wild relatives of these crops or insert exotic genes through genetic engineering to make host plant resistance a viable component of integrated pest management. Host plant resistance is compatible with all the other components of pest management, although pest resistant varieties at times may be incompatible with the natural enemies *e.g.*, varieties of chickpea and pigeonpea with glandular trichomes and long hairs or have indirect adverse effects through suboptimal prey.

10.2.1.3 Biological control

There is voluminous information on parasitism and to a lesser extent on predation of insect pests on 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 the most important larval parasitoid of *H. armigera* on chickpea in India (Pawar *et al.,* 1986). Tachinids parasitize late-instar *H. armigera* larvae, but result in little reduction in larval density. *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. There are a few reliable estimates of pre-pupal and pupal mortality of *H. armigera*. Prospects for biological control in cowpea have been summarized by Tamò *et al.* (2003, 2012). The pod borer *M. vitrata*, whose center of origin is the Tonkin region in South East Asia, has a much greater diversity of parasitoids in that region than in Africa (Long and Hoa, 2012). Of particular interest for redistribution in Africa is the ovo-larval parasitoid, *Phanerotoma philippinensis* Ashmead (and a complex of *Therophilus* species dominated by *T. javanus* (Bhat & Gupta), which has already been reported to control *M. vitrata* in Indonesia by Kalshoven and van der Vecht (1950). The parasitoid *Trichogrammatoidea eldanae* Viggiani attacking eggs of *M. vitrata* has been studied for its potential for augmentative releases (Tamò *et al.*, 2003). Inoculative releases of the parasitoid, *Ceranisus femoratus* Gahan against *M. sjostedti* were carried out in Benin, Ghana and Nigeria, leading to its establishment. In Benin, thrips population studies after releases indicated up to 43% reduction of larval abundance on selected leguminous wild host plants (Tamò *et al.*, 2012). Surveys to assess the impact of this parasitoid on overall reduction of thrips, and subsequent increase in cowpea yield, are currently on-going. In Syria, *Opius monilicornis* Fischer has been found to be the most effective parasitoid of chickpea leafminer, parasitising up to 70% of the larvae (Mardini *et al.*, 1999). 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). Although effective in large numbers, the high cost of large-scale production precludes their economic use in biological control (King *et al.*, 1986).

Biological control is compatible with cultural practices and host plant resistance to insects, except in a few cases. However, parasitoids and predators are not compatible with synthetic pesticides. One of the major problems of biological control is the lag time between release of natural enemies and their effect on bringing the pest populations below economic threshold levels. In addition, there are major issues related to their mass production and delivery system. As a result, the effects of biological control are not as distinct as that of synthetic insecticides. Once the natural enemies are established, they exercise a continuous and cumulative effect on pest populations. Since host plant resistance can have considerable influence on the activity and effectiveness of natural enemies, efforts should be made to identify crop cultivars that are compatible with the natural enemies of crops pests in different agro-eco-systems. Therefore, biological control has to be carefully knitted into the integrated pest management program in respective grain legume crops.

10.2.1.4 Biopesticides

There is considerable information on entomophagous pathogens against pod borers, *H. armigera* and *H. punctigera*, although these tactics have not provided a viable alternative to synthetic insecticides. Spraying *Bacillus thuringiensis* (*Bt*) (Berliner) in the evenings 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 by *H.armigera* on chickpea compared to 16.3% damage in untreated control plots (Saxena and Ahmad, 1997). In Australia, a commercially available NPV has been tested on cotton, 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). Vegetable oils, neem oil and karanj oil provide effective protection against bruchid damage in pulses (Reddy *et al.*, 1996). Karanj oil, and leaf and seed extracts act as oviposition deterrents (Kumar and Singh, 2002). Neem oil has also been found to reduce chickpea leaf miner infestations, and has a less negative effect on the larval parasitoids (El Bouhssini *et al.*, 2008a).

A novel *Maruca vitrata* multi-nucleopolyhedrovirus (*Mavi*MNPV) was reported for the first time from Taiwan (Lee *et al.*, 2007) as a specific entomopathogenic baculovirus, and subsequently introduced to West Africa for assessing its potential against local populations of *M. vitrata.* Experiments were carried out in Benin, Burkina Faso, Niger and Nigeria, yielding promising results (Tamò *et al.*, 2012). More recently, field trials to assess the performance of mixtures of botanical pesticides (Neem and Jatropha oil) and *Mavi*MNPV indicated a synergistic effect, reducing not only the target *M. vitrata*, but also aphids, and thrips populations (Sokame *et al.*, 2013). There is a need for a greater understanding of the effect of climate change on the efficacy and persistence of biopesticides for pest management. Biopesticides have given very impressive results under laboratory and greenhouse conditions. However, their effectiveness is not comparable to synthetic pesticides under field conditions as their efficacy often depends on environmental conditions. Biopesticides are compatible with cultural practices, host plant resistance, and synthetic pesticides, except in a few cases. One of the major problems of microbial pesticides is their slow rate of action. They often have short residual effect, and there are problems associated with quality control and delivery system.

10.2.1.5 Chemical control

Management of insect pests in grain 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. As a result, it has not been possible to use economic thresholds for pest management. 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, and it shown resistance to organo-chlorine, organophosphates, carbamates and synthetic pyrethroids in different parts of the world (Daly *et al.*, 1988; Gunning *et al.*, 1996; Armes *et al.*, 1996; Kranthi *et al.*, 2002; Ahmad *et al.*, 1997a,b; 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).

Chemical control is one of the most effective weapons for pest management. However, large-scale and repeated application of highly toxic insecticides leads to development of resistance, pesticide residues in the produce, and adverse effects on the natural enemies. Under heavy pest infestations, they are the only solution to provide an immediate relief from depredations of the pests. However, they must be used rationally, and timing of pesticide applications is most important to derive the maximum benefit. They are compatible with other components of pest management, except the natural enemies.

10.2.1.6 Transgenic resistance

Progress in developing transgenic plants of food legumes has been reviewed by Popelka *et al.* (2004). Efforts have been made to develop chickpea plants with *Bt* d-endotoxin genes for resistance to *H. armigera* (Kar *et al.*, 1997; Romeis *et al.*, 2004; Acharjee *et al.*, 2010). Transgenic pigeonpea plants with *cry1Ab* and soybean trypsin inhibitor (SBTI) genes have been tested against *H. armigera* (Gopalaswamy *et al.*, 2008). Transgenic chickpea and cowpea expressing cowpea trypsin inhibitor and a-amylase inhibitor (Shade et al., 1994; Schroeder *et al.*, 1995; Sarmah *et al.*, 2004; Luthi *et al.*, 2013) with resistance to bruchids has also been developed. Efforts are also underway to develop and test transgenic cowpea for resistance to spotted pod borer (Popelka *et al.*, 2004; Adesoye *et al.*, 2008), and test the transgenic plants under field conditions in West Africa (Higgins, 2007). Commercialization of transgenic plants with resistance to pod borers will revolutionize the production of chickpea, pigeonpea and cowpea, and provide a new tool for integrated pest management in grain legumes (Sharma, 2009).

Transgenic plants will provide one of the most effective weapons to tackle pest problems in grain legumes, particularly the pod borers, which are difficult to control even with insecticides. Since the level of host plant resistance in the cultivate germplasm are quite low, it is important to develop and deploy transgenic pulses with resistance to key pests. Since transgenic chickpea and cowpea are already available, efforts should be made to make this technology available to farmers in SAT Asia and Africa. Transgenic crops can be effectively deployed in combination with other components of pest management in an integrated pest management program, and we possibly can realize the similar gains in productivity as has been the case with transgenic cotton.

10.3 IPM-Omics

In recent years, genomic tools were applied to the study of pest populations for supporting development and deployment of IPM strategies (Agunbiade *et al.*, 2012a). This new systems approach in IPM, called IPM-omics, will be used to better guide *e.g.* releases of biological control agents suitable to specific populations of the target pest, and application of bio-pesticides. One practical application of IPM-omics is the recent study on the spatial genetic differentiation of *M. vitrata* in West Africa (Agunbiade *et al.*, 2012b). This study revealed genetically different populations based on limited gene-flow, possibly because of the South-North host switch during the rainy season as suggested by

Bottenberg *et al.*, 1997. On the deployment side, IPM-omics will provide scalable solutions, including the use of novel approaches in educational contents such as cellphone video animations (Bello-Bravo *et al.*, 2012). IPM-omics should also help in gene deployment strategies and target resistant varieties based on geographical distribution of virulent populations/biotypes.

10.4 Conclusions

There is a need to gain a thorough understanding of the factors that lead to heavy losses in food legumes. 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 vital role in IPM. Cultural practices that reduce the intensity of insect pests are another important element of pest control. Diversified cropping systems that enhance the activity and abundance of natural enemies should be popularized among the farmers. Insecticides provide quick and effective pest control in food legumes. Neem seed kernel extract, *Bt*, and 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. There is a need for a greater understanding of the effect of climate change on the efficacy of natural enemies, host plant resistance to insects, biopesticides and synthetic insecticides, their persistence in the environment to develop effective strategies for pest management in grain legumes in future.

References

Acharjee, S., Sarmah, B.K., Kumar, P.A., Olsen, K., Mahon Moar, W.J., Moore, A., and Higgins, T.J.V. (2010). Expression of a sequence-modified *cry2Aa* gene for resistance to *Helicoverpa armigera* in chickpea (*Cicer arietinum* L.). *Plant Science* 178, 333-339.

Adesoye, A., Mtachuka, J. nad Togun, A. (2008). *Cry1Ab* transgenic cowpea obtained by nodal electroporation. *African journal of Biotechnology* 7, 3200-3210.

Agunbiade, T., Steele, L., Coates, B. S., Gassmann, A., iMargam, V. M., Ba, M., Dabire, C., Baoua, I., Bello-Bravo, J., Seufferheld, F., Sun, W., Tamò, M., and Pittendrigh, B. R. (2012a). IPM-omics: from genomics to extension for integrated pest management of cowpea. In "Innovative research along the cowpea value chain. Proceedings of the 5th World Cowpea Research Conference" (O. Boukar, O. Coulibaly, C. Fatokun, K. Lopez, M. Tamò, Eds.). 26 September – 1 October 2010. pp. 231-248. Saly, Senegal.

Agunbiade, T. A., Kim, K. S., Forgacs, D., Margam, V. M., Murdock, L. L., Ba, M. N., Binso-Dabire, C. L., Baoua, I., Ishiyaku, M. F., Tamò, M., and Pittendrigh, B. R. (2012b). The spatial genetic differentiation of the legume pod borer, *Maruca vitrata* F. (Lepidoptera: Crambidae) populations in West Africa. *Bulletin of Entomological Research* 102, 589-599.

Ahmad, M., Arif, M. I., and Attique. M. R. (1997a). Patterns of resistance to organophosphate insecticides in field populations of *Helicoverpa armigera* in Pakistan. *Pesticide Science* 55, 626-632.

Ahmad, M., Arif, M. I., and Attique. (1997b). Pyrethroid resistance of *Helicoverpa armigera* (Lepidoptera: Noctuidae) in Pakistan. *Bulletin of Entomological Research* 87, 343-347.

Armes, N. J., Jadhav, D. R., and De Souza, K. R. (1996). A survey of insecticide resistance in *Helicoverpa armigera* in the Indian sub-continent. *Bulletin of Entomological Research* 86, 499-514.

Baker, G. H. (1990a). Natural enemies of pea weevil, *Bruchus pisorum* (Bruchidae), worthy of consideration as biological control agents. In "Workshop Proceedings: National Pea Weevil Workshop" (A. M. Smith, Ed.). pp. 80-83. Victoria Department of Agriculture and Rural Affairs, Melbourne, Australia.

Baker, G. H. (1990b). Future research on biological control of pea weevil, *Bruchus pisorum* (Bruchidae). In "Workshop Proceedings: National Pea Weevil Workshop" (A. M. Smith, Ed.). pp. 84-86.Victoria Department of Agriculture and Rural Affairs, Melbourne, Australia.

Bello-Bravo, J., Seufferheld, F., Agunbiade, T., Steele, L. D., Guillot, D., Ba, M. N., Binso-Dabire, C. L., Baoua, I., N'Diaye, M., Tamò, M., and Pittendrigh B. R. (2012). Scientific Animations Without Borders™: cell-phone videos for cowpea farmers. In"Innovative research along the cowpea value chain. Proceedings of the 5th World Cowpea Research Conference" (O. Boukar, O. Coulibaly, C. Fatokun, K. Lopez, M. Tamò, Eds.)., 26 September – 1 October 2010. pp. 369-380. Saly, Senegal.

Bhagwat, V. R., Aherker, S. K., Satpute, V. S., and Thakre, H. S. (1995). Screening of chickpea (*Cicer arietinum* L.) genotypes for resistance to *Helicoverpa armigera* (Hub.) and its relationship with malic acid in leaf exudates. *Journal of Entomological Research* 19, 249-253.

Bhatnagar, V. S., Sithanantham, S., Pawar, C. S., Jadhav, D. R., Rao, V. K., and Reed. W. (1983). Conservation and augmentation of natural enemies with reference to IPM in chickpea and pigeonpea. In "Proceedings of the International Workshop on Integrated Pest Control in Grain Legumes", 4-9 April 1983. pp. 157–180. Empresa Braseleira Pesquisa Agropocuria (EMRAPA), Goiania, Brazil.

Bottenberg, H., Tamò, M., Arodokoun, D., Jackai, L. E. N., Singh, B. B., Youm, O. (1997). Population dynamics and migration of cowpea pests in northern Nigeria: implications for integrated pest management. In "Advances in cowpea research". Co-publication of International Institute of Agriculture (IITA) and Japan International Center for Agricultural Sciences (JIRCAS). (B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, and L. E. N. Jackai, Eds.). pp. 271-284.IITA, Ibadan, Nigeria.

Burikam, I., Marasri, P., and Pompranee, P. (1998). Resistance to synthetic pyrethroids of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) in Thailand. *Thai Journal of Agricultural Science* 31, 174-183.

Bwye, A. M., Proudlove, W., Berlandier, F. A., and Jones, R. A. C. (1997). Effects of applying insecticides to control aphid vectors and cucumber mosaic virus in narrow-leafed lupins (*Lupinus angustifolius*). *Australian Journal of Experimental Agriculture* 37, 93-102.

Chen, W., Sharma, H.C. and Muehlbauer, F. (Eds.). (2011). Compendium of Chickpea and Lentil Diseases and Pests (Chen W, Sharma HC and Muehlbauer F, eds.). St Paul, Minnesota, USA: The American Phytopathological Society. 165 pp.

Clement, S. L, Wightman, J.A., Hardie, Bailey, P. Baker, G. and McDonald, G. (2000). Opportunities for integrated management of insect pests of grain legumes. In "Linking Research and Marketing Opportunities for Pulses in the 21st Century". pp. 467-480. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Clement, S. L., Cristofaro, M., Cowgill, S. E. and Weigand, S. (1999). Germplasm resources, insect resistance, and grain legume improvement. In "Global Plant Genetic Resources for Insect Resistant Crops" (S. L. Clement, and S. S. Quisenberry, Eds.). pp. 131-148. CRC Press, Boca Raton, Florida, USA.

Daly, J. C., Fisk, J.H., and Forrester, N.W. (1988). Selective mortality in field trials between strains of *Heliothis armigera* (Hubner) (Lepidoptera: Noctuidae) resistant and susceptible to synthetic pyrethroids: functional dominance of resistance and age-class. *Journal of Economic Entomology* 81, 1000-1007.

Das, S. B. (1998). Impact of intercropping on *Helicoverpa armigera* (Hub.): incidence and crop yield of chickpea in West Nimar Valley of Madhya Pradesh. *Insect Environment* 4, 84–85.

Das, S. B., and Kataria, V.P. (1999). Relative susceptibility of chickpea genotypes against *Helicoverpa armigera* (Hubner). *Insect Environment* 5, 68–69.

Deshmukh, R. B., Mhase, L.B., Aher, R.P., Bendre, N. J., and Kolte, T.B. (1996a). High-yielding, wilt-resistant chickpea cultivar Vijay for central zone of India. *International Chickpea and Pigeonpea Newsletter* 3, 15–17.

Deshmukh, R. B., Mhase, L. B., Aher, R. P., Bendre, N.J., and Kolte, T.B. (1996b). Vishal - a bold-seeded, wilt-resistant, high-yielding chickpea variety for western Maharashtra, India. *International Chickpea and Pigeonpea Newsletter* 3, 14–15.

Dhaliwal, G. S., and Arora, R. (1994). Trends in Agricultural Insect Pest Management. Commonwealth Publishers, New Delhi, India.

El Bouhssini, M., Mardini, K., Babi, A., Malhotra, R. S., Joubi, A., and Kagka, N. (2008a). Effects of planting dates, varieties and insecticides on chickpea leaf miner (*Liriomyza cicerina* R.) infestation and the parasitoid *Opius monilicornis* F. *Crop Protection* 27, 915-919.

El Bouhssini, M., Sarker, A., Erskine, W., and Joubi , A. (2008b). First sources of resistance to Sitona weevil (*Sitona crinitus* Herbst) in wild Lens species. *Genetic Resources and Crop Evolution* 55, 1-4.

Erskine, W., Tufail, M., Russell, M. C., Rahman, M. M., and Saxena, M. C. (1994). Current and future strategies in breeding lentil for resistance to biotic and abiotic stresses. *Euphytica* 73, 127-135.

Fitt, G. P. (1989). The ecology of *Heliothis* species in relation to agroecosystems. *Annual Review of Entomology* 34, 17-52.

Fitt, G. P., and Cotter, S. C. (2005). The *Helicoverpa* problem in Australia: biology and management. In "*Heliothis/Helicoverpa* Management: Emerging Trends and Strategies for Future Research" (H. C. Sharma, Ed.). pp. 45-61. Oxford and IBH Publishing, New Delhi, India.

Gopalaswamy, S. V. S., Sharma, H. C., Subbaratnam, G. V., and Sharma, K. K. (2008). Field evaluation of transgenic pigeonpea plants for resistance to *Helicoverpa armigera*. *Indian Journal of Plant Protection* 36, 228-234.

Gunning, R. V., Moores, G. D., and Devonshire, A. L. (1996). Esterases and fenvalerate resistance in a field population in Australian *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae). *Pesticide Biochemistry and Physiology* 54, 12-23.

Hegde, R., and Lingappa, S. (1996). Effect of intercropping on incidence and damage by *Helicoverpa armigera* in pigeonpea. *Karnataka Journal of Agricultural Sciences* 9, 616–621.

Higgins, T. J. (2007). Bt Cowpea with Protection against Pod-borer for Transfer to Africa. Final Report to the Rockefeller Foundation, CSIRO Plant Industry, Canberra, Australia.

Horne, J., and Bailey, P. (1991). *Bruchus pisorum* L. (Coleoptera: Bruchidae) control by knockdown pyrethroid in field peas. *Crop Protection* 10, 53-56.

Jackai, L. E .N. (1990). Screening of cowpeas for resistance to *Clavigralla tomentosicollis* Stal. (Hemiptera: Coreidae). *Journal of Economic Entomology* 83, 300-305.

Javaid, I., Dodson, R. B., Hashem, F. M., Joshi, J.M., and Allen. A. L. (2005). Effect of insecticide spray applications, sowing dates and cultivar resistance on insect pests of cowpea in the Delmarva region of United States. *Journal of Sustainable Agriculture* 26, 57-68.

Kalariya, G. B., Judal, G. S. and Patel, G. M. (1998). Reaction of pigeonpea genotypes against important insect pests. *Gujarat Agricultural University Research Journal* 23, 33–38.

Kalshoven, L. G .E., and van der Vecht, J. (1950). De plagen van de culturgewassen in Indonesië. 512 pp. Van Hoeve, La Haye.

Kar, S., Basu, D., Das, S. Ramkrishnan, N. A., Mukherjee, P., Nayak, P., and Sen, S. K. (1997). Expression of CryIA(c) gene of *Bacillus thuringiensis* in transgenic chickpea plants inhibits development of pod borer (*Heliothis armigera*) larvae. *Transgenic Research* 6, 177-185.

King, E. G., Baumhover, A., Bouse, L. F., Greany, P., Hartstack, A. W., Hooper, K. R., Knipling, E. F., Morrison, R. K., Nettles, W. C., and Powell. J. E. (1986). Augmentation of entomophagous arthropods. In "Theory and Tactics of *Heliothis* Population Management" (S. J. Johnson, E. G. King, and J. R. Bradley, Eds.). pp. 116-131. Cultural and Biological Control Southern Cooperative Series Bulletin 316.

Kranthi, K. R., Jadhav, D. R., Kranthi, S., Wanjari, R. R., Ali, S., and Russell, D. A. (2002). Insecticide resistance in five major insect pests of cotton in India. *Crop Protection* 21, 449-460.

Kumar, M., and Singh. (2002) Potential of *Pongamia glabra* Vent. as an insecticide of plant origin. Biological Agriculture and R. *Horticulture* 20, 29-50.

Lal, S. S. (1987). Insect pests of mung, urid, cowpea and pea and their management. In "Plant Protection in Field Crops" (M. Veerabhadra Rao, and S. Sithanantham, Eds.). pp. 185 202. Plant Protection Association of India, Rajendarnagar, Hyd-erabad, Andhra Pradesh, India.

Lateef, S. S. (1985). Gram pod borer (*Heliothis armigera* (Hub.) resistance in chickpea. *Agriculture, Ecosystem, and Environment* 14, 95-102.

Lateef, S. S., and Sachan, J. N. (1990). Host plant resistance to *Helicoverpa armigera* (Hub.) in different agro-economical conditions. In "Chickpea in Ninetees: Proceedings of the Second International Workshop on Chickpea", 4-8 Dec 1989. pp. 181-189. International Crops Research Insitute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.

Lateef, S. S., and Pimbert, M. P. (1990). The search for host plant resistance of *Helicoverpa armigera* in chickpea and pigeonpea at ICRISAT. In "Proceedings of the Consultative Group Meeting on the Host Selection Behavior of *Helicoverpa armigera",* 5-7 March 1990. pp. 14-18. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India.

Lee, S. T, Srinivasan, R., . Wu, Y. J., and Talekar, N. S. (2007). Occurrence and characterization of a nucleoplyhedrovirus from *Maruca vitrata* (Lepidoptera: Pyralidae) in Taiwan. *BioControl* 52, 801–819.

Long, K. D., and Hoa, D. T. (2012). Notes on parasitoid assemblage reared from larvae of legume pod borers *Maruca vitrata* (Fabricius) and *Etiella zinckenella* Treitschke. *Journal of Biology (Vietnam)* 34, 48-58.

Luthi, C., Alvarez-Alfageme, F., Ehlers, J.D., Higgins, T.V.J., and Romeis, J. (2013). Resistance of á–AI-I transgenic chickpea (*Cicer arietinum*) an cowpea (*Vigna unguiculata*) dry beans to bruchid beetles (Coleoptera: Chrysomellidae). *Bulletin of Entomological Research*. Doi: 10.1077/S0007485312000818.

Mahapatro, G. K., and Gupta. G. P. (1999). Evenings suitable for spraying *Bt* formulations. *Insect Environment* 5, 126-127.

Malhotra, R. S., El Bouhssini, M., and Joubi, A. (2007). Registration of seven improved chickpea breeding lines resistant to leaf miner. *Journal of Plant Registrations* 1(2), 145-146.

Mardini, K., El Bouhssini, M., and Babi, A. (1999). Preliminary study of two parasitoids *Diglyphus isaea* and *Opius monilicornis* on larvae of chickpea leafminer *Liriomyza cicerina* R. in Syria. *Research Journal of Aleppo University* 47-54.

Michael, P. J., Dhalival, S. S., and Mangano, G. P. (1990). Experimenting with chemical control of the adult pea weevil, *Bruchus pisorum* (L.), on field pea crops. In "Workshop Proceedings: National Pea Weevil Workshop" (A. M. Smith, Ed.). pp. 34-40. Victoria Department of Agriculture and Rural Affairs, Melbourne, Australia.

Mohammd, G., and Rao, A. S. (1999). Evaluation of some new insecticides on *Helicoverpa armigera* (Hubner) in pigeonpea. *International Chickpea and Pigeonpea Newsletter* 6, 46-47.

Murray, D. A. H., and Zalucki, M. P. (1990). Survival of *Helicoverpa punctigera* (Wallengren) and *H. armigera* (Hubner) (Lepidoptera: Noctuidae) pupae submerged in water. *Journal of Australian Entomological Society* 29, 91-192.

Parsai, S. K. (1996). Studies on pod fly and pod borer damage in certain medium/late maturing varieties of pigeonpea. *Bhartiya Krishi Anusandhan Patrika* 11, 117-120.

Pawar, C. S., Bhatnagar, V. S., and Jadhav, D. R. (1986). *Heliothis* species and their natural enemies, with their potential for biological control. *Proceedings of the Indian Academy of Science (Animal Science)* 95, 695-703.

Popelka, J. C., Terryn, N., and Higgins, T. J. (2004). Gene technology for grain legumes: can it contribute to the food challenge in developing countries? *Plant Science* 167, 195-206.

Ranga Rao, G. V., Chari, M. S., Pawar, Sharma, O. P., and Rameshwar Rao, V. (2005). *Helicoverpa* management; Successes and failures – lessons for the future. In "*Heliothis/Helicoverpa* Management: Emerging Trends and Strategies for Future Research" (H.C. Sharma, Ed.). pp. 431-452. Oxford and IBH, New Delhi, India.

Reddy, V. S., Babu, T. R., Hussaini, S. H., and Reddy, B. M. (1996). Effect of edible and non-edible oils on the development of pulse beetle, *Collasobruchus chinensis* L. and on viability of mungbean seeds. *Pest Management and Economic Zoology* 2, 15-17.

Rembold, H., and Tober, H. (1985). Kairomones as pigeonpea resistance factors against *Heliothis armigera*. *Insect Science and its Application* 6, 249-252.

Rembold, H., Wallner, P., Kohne, A., Lateef, S.S., Grune, M., and Weigner. C. H. (1990). Mechanism of host plant resistance with special emphasis on biochemical factors. In, "Chickpea in the Nineties: Proceedings of the Second International Workshop on Chickpea Improvement", 4–8 Dec 1989. pp. 191–194. International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India/International Center for Agricultural Research in the Dry Areas, Alleppo, Syria.

Romeis, J., and Shanower, T. G. (1996). Arthropod natural enemies of *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) in India. *Biocontrol Science and Technology* 6, 481-508.

Romeis, J., Sharma, H.C., Sharma, K.K., Das, S., and Sarmah, B.K. (2004). The potential of transgenic chickpea for pest control and possible effects on non-target arthropods. *Crop Protection* 23, 923-938.

Rummel, D. R., and Neece, K. C. (1989). Winter survival of *Heliothis zea* (Boddie) in cultivated soil in the southern Texas High Plains. *Southwestern Entomologist* 14, 117-125.

Sarmah, B. K., Moore, A., Tate, W., Molvig, L., Morton, R. L., Rees, D. P., Chiaiese, P., Chrispeels, M. J., Tabe, L.M., and Higgins T. J. (2004). Transgenic chickpea seeds expressing high levels of amylase inhibitor. *Molecular Breeding* 14, 73-82.

Sawicki, R. M., and Denholm, I. (1987). Management of resistance to pesticides in cotton pests. *Tropical Pest Management* 33, 262-272.

Saxena, H., and Ahmad, R. (1997). Field evaluation of *Beauveria bassiana* (Balsamo) Vuillemin against *Helicoverpa armigera* (Hubner) infecting chickpea. *Journal of Biological Control* 11, 93-96.

Shade, R. E., Schroeder, H. E., Pueyo, J. J., Tabe, L. M. , Murdock, L. L., Higgins, T. J. V., and Chrispeels, M. J. (1994). Transgenic pea seeds expressing a-amylase inhibitor of the common bean are resistant to bruchid beetles. *Bio/Technology* 12, 793-796.

Schroeder, H. E., Gollasch, S., Moore, A., Tabe, L.M., Craig, S., Hardie, D.C., Chrispeels, M.J., Spencer, D., and Higgins, T.J.V. (1995). Bean alpha-amylase inhibitor confers resistance to pea weevil (*Bruchus pisorum*) in transgenic peas (*Pisum sativum* L.). *Plant Physiology* 107, 1233-1239.

Sharma, H. C. (2001). Crop Protection Compendium: *Helicoverpa armigera*. Electronic Compendium for Crop Protection. 72 pp. CAB International, Wallingford, U.K.

Sharma, H. C. (ed.). (2005). *Heliothis/Helicoverpa* Management: Emerging Trends and Strategies for Future Research. 469 pp. Oxford and IBH, New Delhi, India.

Sharma, H. C. (2009). Applications of Biotechnology in Pest Management and Ecological Sustainability. 526 pp. Boca Raton, Florida, USA: CRC Press, Taylor and Francis.

Sharma, H. C., and Pampapathy, G. (2004). Effect of natural plant products, brassinolide, and host plant resistance in combination with insecticides on pod borer, *Helicoverpa armigera* (Hubner) damage in pigeonpea, *Cajanus cajan* (L.) Millsp. *Indian Journal of Plant Protection* 32, 40-44.

Sharma, H.C., Srivastava, C.P., Durairaj, C. and Gowda, C.L.L. (2010) Pest Management in grain legumes and climate change. In: Climate Change and Management of Cool Season Grain Legume Crops (Yadav SS, et al., eds.), pp. 115-139. Dordrecht, The Netherlands: Springer Science + Business Media.

Sharma, H. C., Saxena, K. B., and Bhagwat, V. R. (1999). Legume Pod Borer, *Maruca vitrata*: Bionomics and Management. 35 pp. Information Bulletin 55. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India.

Sharma, H. C., Ahmad, R., Ujagir, R., Yadav, R. P., Singh, R., and Ridsdill-Smith, T. J. (2005a). Host plant resistance to cotton bollworm/legume pod borer, *Heliothis*/*Helicoverpa*. In: "*Heliothis/Helicoverpa* Management: Emerging trends and Strategies for Future Research" (H. C. Sharma, Ed.). pp. 167-208. Oxford and IBH Publishers, New Delhi, India.

Singh, J. P., and Gupta, G. P. (1997). Evolution of effective and economical spray schedules based on spray initiation against bollworm complex in cotton. *Pesticide Research Journal* 9, 175-184.

Singh, K. B., and Weigand, S. (1996). Registration of three chickpea leaf miner resistant lines: ILC 3800, ILC 5901, and ILC 7738. *Crop Science* 36, 472.

Singh, S. R. (1978). Resistance to pests of cowpea in Nigeria. In: Pests of Grain Legumes: Ecology and Control (S. R. Singh, H. F. van Emden, and J. A. Taylor, Eds.). pp. 267-279. Academic Press, London, UK.

Singh, S. R., and Jackai, L. E. N. (1985). Insect pests of cowpea in Africa: Their life cycle, economic importance, and potential for control. In "Cowpea Research, Production and Utilization" (S. R. Singh, and K. O. Rachie, Eds.). pp. 217-231. John Wiley and Sons, Chichester, UK.

Sokame B. M., Tounou A. K., Datinon B., Dannon E. A., Agboton, C., Srinivasan, R., Pittendrigh, B. R., Tamò, M. (2013). Combined activity of *Maruca vitrata* multi-nucleopolyhedrovirus, *Mavi*MNPV, and oil from neem, *Azadirachta indica* Juss and *Jatropha curcas* L., for the control of cowpea pests. *Crop Protection* (submitted).

Tamò, M., Ekesi, S., Maniania, N. K., and Cherry, A. (2003). Biological control, a non-obvious component of integrated pest management for cowpea. In.: "Biological Control in Integrated Pest Management Systems in Africa" P. Neuenschwander, C. Borgemeister, and J. Langewald, Eds). pp 295-309. CABI Publishing, Wallingford, UK.

Tamò, M., Srinivasan, R., Dannon, E., Agboton, C., Datinon, B., Dabiré, C., Baoua, I., Ba, M., Haruna, B., and Pittendrigh, B.R. (2012). Biological Control: A Major Component for the Long-Term Cowpea Pest Management Strategy. In :Innovative research along the cowpea value chain" (O. Boukar, O. Coulibaly, C. Fatokun, K. Lopez, M. Tamò, Eds.). pp. 249-258. Proceedings of the 5th World Cowpea Research Conference, 26 September – 1 October 2010 Saly, Senegal.

van den Berg, H., Waage, J. K., and Cock, M. J. W. (1988). Natural enemies of *Helicoverpa armigera* in Africa – a review. 81 pp. Commonwealth Agricultural Bureaux, International Institute of Biological Control, Ascot, Berks, UK.

van Emden, H. F., Ball, S. L., and Rao, M. R. (1988). Pest and disease problems in pea, lentil, faba bean, and chickpea. In "World Crops: Cool Season Food Legumes" (R. J. Summerfield, Ed.). pp. 519-534. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Ward, A., and Morse, S. (1995). Partial application of insecticide to broad bean (*Vicia faba*) as a means of controlling bean aphid (*Aphis fabae*) and bean weevil (*Sitona lineatus*). *Annals of Applied Biology* 17, 239-249.

Weigand, S., Lateef, S. S., El Din Sharaf, N., Mahmoud, S. F., Ahmed, K., and Ali, K. (1994). Integrated control of insect pests of cool season food legumes. In "Expanding the Production and Use of Cool Season Food Legumes" (F. J. Muehlbauer, and W. J. Kaiser, Eds.). pp 679-694. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Zalucki, M. P., Daglish, G., Firempong, S., and Twine, P. (1986). The biology and ecology of *Heliothis armigera* (Hubner) and *H. punctigera* Wallengren (Lepidoptera: Noctuidae) in Australia: What do we know? *Australian Journal of Zoology* 34, 779-814.