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Biological control of chickpea pod borer, *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae): A global concern

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ABSTRACT

Chickpea (*Cicer arietinum* L.) is grown widely in the world because the seeds are rich source of protein for the rapidly increasing population. However, the production and productivity of chickpea have been experienced drastically because of biotic and abiotic stresses. It is vulnerable to a broad range of pathogens and the mainly severe pest being gram pod borer, *Helicoverpa armigera*. For the management of this serious pest, application of insecticides has several adverse effects on living organisms and the environment as a whole, the use of biological agents for chickpea improvement appears to be appropriate approach. Various studies by different scholars on the effect of different bio-agents against *H. armigera* have been carried out and found to confer resistance to pod borer. The use of *Bacillus thuringiensis* (Bt) based microbial insecticides have become an integral part of IPM approaches, particularly because these preparations provide an environmentally suitable alternative to the generally hazardeous broad-spectrum chemical insecticides. These bacterial insecticides like Nuclear Polyhedrosis Virus (NPV), which is target specific and exert no effect on beneficial organisms (e.g. parasitoids and predators). Most natural populations of *H. armigera* have at least some degree of infection by species-specific NPVs. When the degree of NPV infection can be enhanced, *H. armigera* larval population can be decimated, without deleterious effects on any other organisms. Various potentially effective parasitoids, like ichneumonid, Campoletis chloridae and Trichogramma spp., are found parasitizing eggs and larvae of *H. armigera* infesting chickpea. Various insectivorous birds and use of bird perches have long been observed to be effective predators of *H. armigera* larvae. Similarly various plant extracts have shown insecticidal properties and can be used effectively on field crops. Use of different bio-agents and botanicals having easy ways of formulation, cost effective, environmentally suitable and no or minimal deleterious effect on non target organisms, worthy of inclusion in most IPM packages.

***Keywords*:** bioagents; *Cicer arietinum*; *Helicoverpa armigera*; integrated pest management

1. INTRODUCTION

Chickpea was first produced in the Middle East about 7,000 years ago. At present, it is produced in over 40 countries represented in all continents. However, the most important chickpea producing countries are India, Turkey, Pakistan, Iran, Mexico, Australia, Ethiopia, Myanmar, and Canada. Chickpea is currently grown on about 11 million hectares worldwide with 65 and 8 per cent share belonging to India and Pakistan, respectively. Average annual production of chickpea is about 9 million tones with 95 per cent of chickpea cultivation and consumption occurring in the developing countries.

In India, chickpea was grown on 9.21 m ha area with a production and productivity of 8.88 mt and 995 kg ha^{-1}, respectively [1]. India is the largest producer of chickpea in the world sharing 68 and 70 per cent of the total area (13.20 m ha) and production of 11.62 mt, respectively [2]. It is also among the most important food legumes in Ethiopia both in terms of area coverage and volume of production [3]. Ethiopia is the largest producer of chickpea in Africa accounting for about 46 per cent of production during 1994-2006 [4] and seventh largest producer in worldwide [5]. The country is also considered as the secondary centre of diversity for chickpea [6,7]. The diverse agro-climatic conditions in Ethiopia make it very suitable for growing chickpeas. Chickpea is widely grown across the highlands and semi-arid regions of Ethiopia and serves as a multi-purpose crop. It has a major role in the daily diet of the rural community and parts of urban population. Currently, it is cultivated in four regions of the country, Amhara, Oromia, Southern Nations, Nationalities and People's Region (SNNPR) and Tigray. Amhara and Oromia regions together produce 93 per cent of total chickpea production in Ethiopia while SNNPR and Tigray produce 3.5 and 3 per cent, respectively.

Chickpea seed is recognized as a valuable source of dietary proteins (18 to 22%), carbohydrate (52 to 70%), fat (4 to 10%), minerals (calcium, phosphorus, iron) and vitamins. Its straw has also good forage value [8]. In addition to its importance in human food and animal feed, chickpea plays an important role in improving soil fertility by fixing the atmospheric nitrogen. It can fix up to 140 kg N per ha from air and meet most of its nitrogen requirement [9].

The production and productivity of chickpea have been experienced drastically because of biotic and abiotic stresses. It is vulnerable to a broad range of pathogens and the mainly severe pest being gram pod borer *H. armigera* (Hubner) (Lepidoptera: Noctuidae). As this insect pest is a serious obstacle and become a global concern for the production of chickpea, eco-friendly and effective pest management options should be practiced. So, this review gives information on biological control methods of *H. armigera* that are practiced across different chickpea producing countries.

Helicoverpa armigra: A GLOBAL CONCERN

Distribution of *H. armigera*

Helicoverpa armigera is a cosmopolitan and widely distributed insect pest in world. It is a serious pest of all legumes. In India, it has been observed to feed on 181 cultivated and uncultivated species belonging to 45 families. *H. armigera* is found in the Palearctic, Oriental, Ethiopian and Australian provinces, south of a line at approximately 52°N. This range occupied by the species includes tropical, dry and temperate climates [10]. The currently reported global distribution of *H. armigera* suggests that the pest may be most closely associated with deserts and xeric shrublands; Mediterranean scrub; temperate broadleaf and mixed forests; tropical and subtropical grasslands, savannas, and shrublands; and tropical and subtropical moist broadleaf forest.

Host range of *H. armigera*

Singh and Balan [11] reported that 47 species of host plants were preferred food with larval survival of 10 to 80 per cent and three (tomato, gram and Egyptian clover) were the most preferred hosts with larval survival of more than 80 per cent. Pawar *et al.* [12] observed 182 plant species as hosts of *H. armigera* of which 56 were heavily damaged and 126 were rarely affected. Likewise, Fitt [13] recorded the crops of maize, sorghum, cotton, Phaseolus, peas, chickpeas, tomatoes, aubergines, capsicum, vicia and, to a lesser extent, trifolium, okras, cabbages, lettuces and strawberries, tobacco, sunflowers, cucurbitaceae and many of the other legumes as host plants of the pest. Venkataiah *et al.* [14] observed the growth and development of *H. armigera* on various host plants and grouped the host plants as most preferred, chickpea, pigeonpea, maize, safflower, sunflower, okra, groundnut, maize; moderately preferred, cotton, cowpea, black gram, tobacco, tomato; less preferred, soybean, mustard, *Solanum* sp. and least preferred, chillies, *Corchorus* sp. and *Xanthium* spp. Jallow and Masaya [15] demonstrated that tomato was a preferred host for *H. armigera* oviposition and neonate survival. The most important crop hosts of which *H. armigera* is a major pest are tomato, cotton, pigeonpea, chickpea, sorghum and cowpea. Other hosts include dianthus, rosa, pelargonium, chrysanthemum, groundnut, okra, peas, field beans, soybeans, lucerne, *Phaseolus* spp., tobacco, potatoes, maize, flax, a number of fruits (Prunus, Citrus), forest trees and a range of vegetable crops [16-19]. It causes appreciable losses in cotton, pigeonpea, tomato, maize, groundnut, sunflower, tobacco besides chickpea [20].

Ravi *et al.* [21] studied that *H. armigera* infests many economically important crops in India, including cotton, pigeonpea, chickpea, sunflower, corn, chilli, tomato and okra. They also examined the relative abundance of *H. armigera* on different host crops within a crop mosaic. Field studies conducted over two growing seasons (2000-2001 and 2001-2002) indicated differences in egg and larval densities among the host plant species. All the host crops supported eggs and larvae of *H. armigera*, but the populations on pigeonpea and chickpea were also significantly greater than on cotton and other host crops. Egg numbers were significantly higher on sunflower, okra and tomato than on cotton, but larval numbers were not significantly different from cotton at comparable times. Both egg and larval numbers on corn and chilli were not significantly different from those on cotton. This study demonstrated that a number of host crops of *H. armigera* support large populations at the same time that cotton is infested.

Morphology and life stages of *H. armigera*

Lifecycle of *H. armigera* take 4-6 weeks from egg to adult in summer and, 8-12 weeks in spring or autumn. The *Helicoverpa* lifecycle stages are egg, larva, pupa and adult (moth) (Fig. 1).

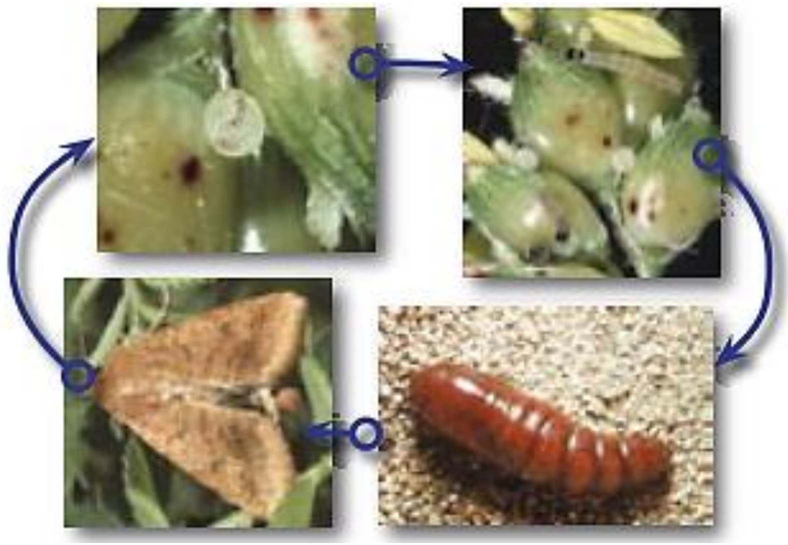

Figure 1. Lifecycle of *Helicoverpa armigera*.

Eggs: The freshly laid eggs of *H. armigera* are yellowish-white and glistening at first but changed to dark brown before hatching [22]. The apical area of egg is smooth and the rest of the surface sculptured in the form of longitudinal ribs (Fig. 2). The incubation period of eggs was 3.37 ± 0.09 days, whereas, the size of eggs varied from 0.42-0.60 mm in length and 0.40-0.55 mm in width on chickpea.

Figure 2. Eggs of *Helicoverpa armigera*.

Larva: Ali *et al.* [22] found that *H. armigera* had six distinct instars in chickpea. The first and second larval instars are yellowish-white to reddish-brown with dark brown to black head capsule. The average duration of corresponding instars were 2.27 ± 0.08 and 2.42 ± 0.08 days, respectively. However, the length and width of these instars were 1.40 ± 0.06 and 0.45 ± 0.01 mm and 3.88 ± 0.11 and 0.75 ± 0.01 mm, respectively. During the first and second instars, the colour of larvae was more uniform and the movement was very little. The average length and width of third, fourth, fifth and sixth instars was 7.90 ± 0.19 and 2.28 ± 0.04 mm; 12.83 ± 0.45 and 2.85 ± 0.04 mm; 20.97 ± 0.61 and 3.25 ± 0.04 mm, 32.50 ± 0.35 and 4.03 ± 0.04 mm, respectively. On the other hand, respective (3^{rd} to 6^{th}) instars complete their larval period within 2.67 ± 0.07, 2.83 ± 0.07, 3.40 ± 0.10 and 3.37 ± 0.11 days, respectively. Cunningham *et al.* [23] and Zalucki *et al.* [24] observed that the full grown larva was straw-yellow to green with lateral brown strips and the head as well as prothoracic legs were dark brown to black in color (Fig. 3). Tubercles and spiracles of the larvae were also brown to black, giving them a spotted appearance. Bhatt and Patel [25] observed that the prolegs develop in third instar stage on 3^{rd}, 4^{th}, 5^{th}, 6^{th} and 10^{th} abdominal segments and remained until last (sixth) larval instar.

Figure 3. *Helicoverpa armigera* larva.

Pre-pupa: Bhatt and Patel [25] reported that pre-pupal stage is shorter and stouter with uniform colour. The full grown larva suspends its activities, becomes sluggish and stops feeding in this stage. The average length and breadth of pre-pupal stage is 21.09±1.02 and 4.26±0.60 days. The average duration of pre-pupa reported was 2.47 ± 0.70 days.

Pupa: The pupa is obtect type with mahogany-brown colour (Fig. 4). Its surface is smooth and it is rounded both anteriorly and posteriorly, with two tapering parallel spines at the posterior tip. The average length and width of pupa was 19.00 ± 0.30 and 5.72 ± 0.08 mm, respectively. However, this stage took minimum and maximum period of 10 and 14 days, respectively [22].

Figure 4. *Helicoverpa armigera* pupa.

Adult: The adult moth was stout-bodied with broad thorax as observed by Cunningham *et al.* [23]. The forewings had a series of dots on the margins and a black comma-shaped marking in the middle underside of each forewing. However, the hind wings were lighter in colour with a broad dark-brown border at the apical end; they had yellowish margins and strongly marked veins (Fig. 5). There was a distinguished colour pattern between male and female moths. Males were greenish-grey in colour, whereas, females with orange-brown and were also identified by the presence of tuft of hairs on the tip of abdomen. Bhatt and Patel [25] reported that the male moths emerge within 9.17 ± 0.42 days and female took 11.74 ± 0.51 days to complete development. The average length and width (with expanded wings) of male and female was as 17.65 ± 0.18 and 34.73 ± 0.59 mm; 20.08 ± 0.38 and 40.93 ± 0.55 mm, respectively.

Figure 5. Adult of *Helicoverpa armigera.*

Fecundity: Sharma [26] observed that the single female laid an average 413.00 ± 1.89 eggs over a reproductive/oviposition period of 4.60-5.80 days. The eggs were laid singly during night time due to nocturnal behavior. Butter and Singh [27] observed that the percentage hatching/viability of eggs was 53.33 ± 0.47 per cent. Jallow and Zalucki [28] reported that female required an average 2.45 ± 0.08, 5.33 ± 0.12 and 2.00 ± 0.05 days for pre-oviposition, oviposition and post-oviposition, respectively.

Nature and extent of damage

It is the most important pest of chickpea in all the chickpea growing areas. Due to heavy infestation of the insect, serious decline in production has been reported by different workers like 21 per cent by [29] and 37.50 per cent by [30]. Chaudhry and Sharma [31] reported that a single larva of *H. armigera* damaged 7-10 per cent pods, caused about 5.4 per cent yield loss, and damaged 6.7 per cent pods and 6.2 per cent grains per meter row length of the gram crop. In Ethiopia it causes 80 per cent pod damage in early sown chickpea [32]; 21 to 36 per cent pod damage in central highlands [33] and 100 per cent pod damage in some localities of Yilmana Densa and Achefer areas in Gojjam in the 1990's [34]. It damages almost all the pods in case of severe damage, but causes nearly 20-30 per cent annual yield losses in Ethiopia. Infestation of this pest was found on 8 to 26 per cent of plants and the number of larvae on infested plants varied from 1 to 4 (average 2.6) per plant [35]. The extent of damage caused by *H. armigera* to chickpea depends on the number of larval pests per plant and on its developmental stages [36].

In India, yield losses caused by *H. armigera* are in the range of 20 to 30 per cent and sometimes rise to 75 per cent in chickpea which is increased even to 90 per cent in

Bangladesh [37]. In Nepal, it is increasingly becoming a severe threat of spring season tomato for the last few years [38]. The caterpillars are voracious feeders of developing grains in case of chickpea an average of 7.5 per cent pod damage and also suggested that a single larva can completely destroy 30-40 pods before it reaches to maturity [39]. *H. armigera* causes an estimated loss of $ 927 million in chickpea and pigeonpea and possibly over $ 2 billion on different crops in the semi-arid tropics with estimated loss of $ 2 billion, despite insecticide application cost ($ 1 billion annually) in Asia and similarly in American and Australian continents [40]. Sharma [26] observed that *Helicoverpa zea* caused an estimated loss of $ 927 million in chickpea and pigeonpea, and possibly $ 5 billion on different crops worldwide (Fig. 6).

Figure 6. *Helicoverpa armigera* larva feeding inside a chickpea pod.

Russel *et al.* [41] showed that average losses on account of crop damage by *Helicoverpa* worked out to be 10 to 30 per cent. In Pakistan Sarwar *et al.* [42,43] reported 26.01 to 40.08 per cent and 10.53 to 39.14 per cent crop losses on susceptible and tolerant genotypes, respectively, due to *H. armigera* from early vegetative to poding stage in chickpea.

Biocontrol agents for the management of *Helicoverpa armigera*

A variety of predatory and parasitic insects, spiders, birds, bats, rodents and diseases attack *Helicoverpa* at different stages of its lifecycle. Natural enemies will rarely eradicate all eggs or larvae, but may reduce infestations to below economic threshold if predators and parasitoids are not disrupted by broad-spectrum insecticides. The amount of disruption that insecticides cause to natural enemy activity varies depending on which chemicals are used and which natural enemies are active. There are a range of potential options for control of *H. armigera* in chickpea. Among these use of different biological control agents are the most effective, inexpensive and environmentally safest methods for the control of many biotic stresses including *H. armigera* and here below discussed individually:

Pathogens, Predators and Parasitoids

Bacteria

In the developed world, use of *Bacillus thuringiensis* (Bt) based microbial insecticides have become an integral part of IPM approaches, particularly because these preparations provide an environmentally suitable alternative to the generally hazardous broad-spectrum chemical insecticides. These bacterial insecticides, like nuclear polyhedrosis virus (NPV), target specific insects but do not affect beneficial organisms (e.g. parasitoids and predators). With the development of more effective *Bt* strains and improved commercial formulations, these insect pathogens are gaining increasing international support for use against agricultural insect pests. The efficacy of *Bt*, which can be enhanced by incorporation of suitable quantities of acids, salts, oils, adjuvants, thuringiensin (exotoxin of *Bt*) and chemical insecticides, against lepidopteran pests including *H. armigera* has been demonstrated [44-47].

In Pakistan, extensive studies were conducted on evaluation of bio-efficacy of some indigenous and exotic strains of *B. thuringiensis* and commercial preparations [48,49,50,51]. This resulted in the development of a package of *Bt* application technology for management of *H. armigera* infesting chickpea. Application of DiPel 2X and DiPel ES @ 1.6 kg ha^{-1} and 1.5 l ha^{-1}, respectively, at early stages of crop infestation (1^{st}, 2^{nd} and 3^{rd} instar larval infestation) with at least 2 applications at 7 days interval resulted in significant increases in yield of chickpea as compared to controls [50,52,53].

In India, preparations of *Bt* based insecticides, Biobit, Delfin and DiPel together with NPV, showed minimum pod damage (4.2 to 16.7%) as compared to the control (12.4 to 38.6%) ([54]. It appears that *Bt* based insecticides can be made effective IPM tools in the South Asian countries if an awareness is developed among farmers about the critical time and method for their safe application.

Viruses and fungi

Most natural populations of *H. armigera*, and also of other lepidopteran species, have at least some degree of infection by species-specific nuclear polyhedrosis viruses (NPVs). If the degree of NPV infection can be enhanced then the *Helicoverpa* larval population can be decimated, without deleterious effects on any other organisms. HaNPV has been reported to be a viable option to control *H. armigera* in chickpea [55-58].

In Australia, the efficacy of HaNPV in chickpea has been increased by the addition of milk powder, and more recently the additive AminofeedR. Spraying *Bt* formulations in the evening results in better control than spraying at other times of the day [59]. In Australia, specific control of *H. armigera* and *H. punctigera* on chickpea is being achieved using the commercially available HaNPV, with an additive that increases the level of control. *Bt* formulations are also used as a spray to control *Helicoverpa* (Fig. 7).

Figure 7. NPV-infected *Helicoverpa armigera* larva. Larvae infected by NPV crawl to the top of a plant, turn black and liquefy before disintegrating.

In India, scientists have done extensive studies on evaluation of NPVs and developed technologies for successful application of indigenous NPV preparations to combat *H. armigera* infesting chickpea. Thakur [60] applied an NPV preparation @ 1.5 ml^{-1} and obtained 586 kg ha^{-1} grain yield, not significantly different from that with a chemical insecticide (Deltamethrin 2.8 EC applied @ 1.0 ml l^{-1}) (685 kg ha^{-1}) but significantly more than an unsprayed control (330 kg ha^{-1}). Sharma *et al.* [61] reported high *H. armigera* larval mortality in bioagent and chemical insecticide treatments. NPV@ 300 LE ha^{-1} caused 78.7 per cent reduction in larval population, resulting in 10.0 per cent pod damage and high grain yield (1.86 t ha^{-1}), whereas the chemical insecticide Endosulfan 35 EC @ 1200 ml ha^{-1} caused a 70.9 per cent reduction in larval population, resulting in 11.2 per cent pod damage and 1.86 t ha^{-1} grain yield. Many other workers in India have applied of NPV and reported significant reductions in *H. armigera* larval population and accordingly less pod damage in chickpea, as compared to chemical insecticides and control treatments [55,62-65]. Entomopathogenic fungus, *Nomuraea rileyi* (106 spores per ml), results in 90-100 per cent larval mortality, while *Beauveria bassiana* (2.68 × 107 spores per ml) resulted in 6 per cent damage in chickpea compared to 16.3 per cent damage in the untreated control plots [66] (Fig. 8).

Figure 8. Metharizium- infected larva. On larva killed by Metharizium, the green fungus is visible growing out of the larva's body.

Parasitoids and predators

Where chemical insecticides are not used, various parasitoids can be found parasitizing eggs and larvae of *H. armigera* infesting chickpea. These natural enemies can often maintain *H. armigera* populations at sub-threshhold levels. In Bangladesh, Nepal, Pakistan and India, it is estimated that less than 10 per cent of farmers currently use chemical insecticides on chickpea, which provides scope for evaluation, utilization and enhancement of effective *H. armigera* parasitoids. The ichneumonid, *Campoletis chlorideae* (Uchida), is probably the most important larval parasitoid on *H. armigera* in chickpea in India. *Carcelia illota* (Curran), *Goniophthalmus halli* Mesnil and *Palexorista laxa* (Curran) have also been reported to parasitize up to 54 per cent larvae on chickpea [67,68]. Although Pawar *et al.* [69] reported 31.4 per cent parasitism of *H. armigera* larvae by *C. chlorideae* (Uchida), an ichneumonid, in chickpea at ICRISAT, India. In Bihar state of India, 14.3 to 58.0 per cent parasitism of *H. armigera* larvae by *C. chlorideae* was observed in chickpea fields [70]. In Maharashtra state of India, 14.7 per cent parasitism by *C. chlorideae* on *H. armigera* larvae was observed in a chickpea field [71].

Extensive studies in Pakistan have been conducted on parasitism of *H. armigera* larvae on chickpea by *C. chlorideae* have been undertaken [72-74]. A mean level of 46.5 per cent parasitism was observed at the early stage of the crop (from mid-Oct to Nov). In a laboratory evaluation, 31 to 50 per cent parasitism on *H. armigera* larvae was observed from the 1^{st} to the 4^{th} generation of this parasitoid. Studies on host age susceptibility, with the aim of mass culturing *C. chlorideae*, indicated that 1-5 day old host larvae (1^{st} to 2^{nd} instar) were more susceptible to parasitism (48-59%) than older larvae [47]. Laboratory studies indicated that *C. chlorideae* do not lose vigor or effectiveness as parasites after successive generations maintained in the laboratory [74].

Fortunately, *C. chlorideae* is the only parasitoid capable of parasitizing hosts in the presence of acid exudates, as produced by chickpea foliage, and could prove to be effective in suppressing the host population of *H. armigera* on chickpea crops if economical methods for mass culturing and field application of this parasitoid are evolved. Scientists in Pakistan [73] carried out extensive studies in order to evaluate effectiveness of *C. chlorideae* in parasitizing its host *H. armigera* through successive generation (4 generations) of the parasite, they observed 45.95 per cent parasitism by the 1^{st} generation adults of parasitoid (711 larvae parasitised out of 1724 1^{st} instar larvae exposed to 1^{st} generation parasitism), 30.90% parasitism by the 2^{nd} generation adults of parasitoid (737 larvae parasitised out of 2376 1^{st} instar larvae exposed to 2^{nd} generation parasitism), 52.30% parasitism by the 3^{rd} generation adults of parasitoid (880 larvae parasitised out of 1660 1^{st} instar larvae exposed to 3^{rd} generation parasitism) and 52.53 per cent parasitism by the 4^{th} generation adults of parasitoid (67 larvae parasitised out of 120 1^{st} instar larvae exposed to 1^{st} generation parasitism).

They further reported that male and female emergence ratios of parasitoid from 1^{st} to 4^{th} successive generations were 1.3:1, 2.1:1, 2.9:1 and 20:0 (in this case no female emerged), respectively. In the meantime, however, it is recommended that every endeavor should be made to encourage natural populations of parasitoids. The most obvious way of achieving this is avoidance, to the extent possible, of application of chemical insecticides in and around chickpea crops. Mixed cropping or intercropping with crops such as mustard or linseed should enhance natural *C. chlorideae* populations and thus minimize pod borer damage [75]. Another potentially effective parasitoid of *H. armigera* on chickpea is *Trichogramma* spp., small wasps which attack *H. armigera* eggs [76,77]. However, acid exudation from chickpea foliage discourages activity of this parasitoid [78,79]. At Nagpur, India, Kulat *et al.* [80] conducted experiment and reported that after four releases of 100,000 *Trichogramma chilonis* ha^{-1} none of the 1763 *H. armigera* eggs collected from chickpea during the growing seasons of 1994-96 were found parasitized. The authors attributed the failure in parasitism to either the dry environment or discouragement of the parasite by acidic secretion of the chickpea plants.

Various insectivorous birds have long been observed to be effective predators of *H. armigera* larvae. Predators such as *Chrysopa* spp., *Chrysoperla* spp., *Nabis* spp., *Geocoris* spp., *Orius* spp. and *Polistes* spp. are the most common in India. Provision of bird perches or planting of tall crops that serve as resting sites for insectivorous birds such as myna and drongo helps reduce the numbers of caterpillars. Activity of these birds can be enhanced, and more birds attracted, by placing bird perches in chickpea fields. However, it should be checked that the birds so attracted do not include those which damage chickpea pods themselves. Branches of bamboo make effective bird perches as secondary branches emerge at almost right angles from the main stem, providing convenient perches on bamboo stems inserted into the soil. Use of bird perches is an extremely low cost but potentially effective means of *H. armigera* control, worthy of inclusion in most IPM packages. Managed foraging by domestic poultry, at least near homesteads, can also assist in control of pod borer. In low income rural areas in South Asia where chickpea is grown, children can effectively collect *H. armigera* larvae from chickpea and then destroy them; modest payment can be given for this task.

Botanical pesticides

Dating from traditional practices, various plant extracts have shown insecticidal properties and can be used effectively on field crops. Globally botanical pest management is gaining appreciation because of multiple mode of action such as antifeedant which inhibit normal development of insects, repellant, antijuvenile hormone activity, oviposition/hatching deterrence, antifertility/growth disrupters and chemosterilants [81]. According to Purohit and Vyas [82] about 2121 plant species are reported to use in pest management programs. In Ethiopia, even though with rich floral diversity, about 30 plant species are recorded and most of them are used traditionally for the management of pests [83]. The most well-known and commonly used is azadirachtin isolated from the seed, wood, bark, leaves and fruits of the neem tree (*Azadirachta indica*). *Azadirachtin* has both antifeedant and growth retarding properties and can lead to death at one or the other stage in the life cycle probably by interfering with the neuroendocrine control of metamorphosis in insects [83].

In 1993, some cotton farmers in Yeotimal district of Maharashtra state of India were able to manage *Helicoverpa* pod borer by spraying chilly plus garlic extract. Later, this method was successfully applied to control *Helicoverpa* pod borer on chickpea and pigeonpea. A botanical pesticide method for management of *H. armigera* on cotton was successfully implemented in farmers' fields of two villages (Sadya Tanda and Wanaparthy) in Warangal District, Andhra Pradesh, India in 1997 which in the authors' opinion can also be used to manage this pest infesting chickpea. In Ethiopia, Tebkew *et al*. [84] reported that the capacity of neem extracts prepared from neem seeds collected from Melka woreda has significantly reduced the percentage pod damage; similarly pod damage on treated chickpea was lower than untreated plots [85]. It was observed that the net profit in eco-friendly modules at both the villages was as good as in pesticide loaded module. They further stated that grain yield of chickpea varied considerably due to soil heterogeneity and outbreak of *Helicoverpa* during 1997-98. In Pakistan, research on evaluation of Neem Seed Kernel Extracts (NSKE) against major lepidopterans e.g. *H. armigera, Pectinophora gossypiella* and *Earias* spp. pests of cotton and other high value crops has resulted in the development a registered product named NIMBOKILL 60 EC and this neem product is available in the market at a competitive rate as an IPM tool.

In Ethiopia, authors Lulie and Raja [86] observed that the antifeedant activity of tested plant extracts of neem on the 4^{th} instar larvae and found minimum chickpea pod damage (13.33%) as compared to other treatments and untreated control which was recorded 100 per cent pod damage. They further stated that minimum number of larvae (9.0) was observed in plot allotted for the treatment of NSKE. They have also observed the effect of botanicals on chickpea yield and found that the mean yield of processed chickpea at the end of cropping season was lowest in control plots (419.33g), whereas highest mean yield was obtained from NSKE (781g), followed by Diazinon 60% EC treated plot (719.33g). Similarly, these authors studied the effect of botanicals and chemical pesticides on non target organisms and found that the highest mean number of non target organisms on NSKE treated plots as compared to others.

2. MERITS AND DEMERITS OF BIOCONTROL AGENTS

Merits:

Cost: biological control agents can be inexpensive if permanent establishment (important for low-value crops); expensive if frequent augmentation and cheaper than any other methods.
Duration: use of biological control agents give protection to the crop throughout the crop period (Long-lasting or permanent).
Toxicity: application of biological control agents do not cause toxicity to the plants.
Spectrum: use of biological control agents not only control the disease but also enhance the root and plant growth by way of encouraging the beneficial soil micro flora. It increases the crop yield also.
Easiness: biological control agents are very easy to multiply, handle, manufacture and apply to the target insect pest (The selectivity of biological agents is with few side effects, not broad-spectrum and not totally without impacts when generalists used).
Compatibility: biological control agents can be combined with bio-fertilizers and compatible with most of integrated pest management components.
Non-polluting: application of biological control agents involve no chemical, though sometimes beneficials get too abundant and harmless to human beings and animals (Environmentally safe).
Resistance: biological control agents multiply easily in the soil and leave no residual problem (development of resistance unlikely as beneficials also can evolve).

Demerits:

Constrains management options: may limit use of insecticides.
Speed of action: biological control agents may require considerable time.
Pest elimination: use of biological agents rarely is pest eliminated; problem for pests causing damage at low densities.
Specificity: use of biological control agents may limit commercial potential and use for minor pests.
Predictability: use of biological control agents may be concern about reliability.
Production: for inoculation, availability of biological control agents may be concern.

3. CONCLUSIONS

Chickpea (*Cicer arietinum* L.) is grown widely in the world because the seeds are rich source of protein for the rapidly increasing population. However, the production and productivity of chickpea have been experienced drastically because of biotic and abiotic stresses. It is vulnerable to a broad range of pathogens and the mainly severe pest being gram pod borer, *Helicoverpa armigera*. Due to this chronic problem and greater public awareness of a need for sustainable control practices, biological control will probably be considered and used more frequently as part of a management program. Biological control projects should be carefully selected and conducted by trained professionals. For the management of this serious pest, application of insecticides has several adverse effects on living organisms and the environment as a whole, the use of biological agents for chickpea improvement appears to be appropriate approach. Various studies by different scholars on the effect of different bio-agents against *H. armigera* have been carried out and found to confer resistance to pod borer. The use of *Bacillus thuringiensis* (Bt) based microbial insecticides have become an integral part of IPM approaches, particularly because these preparations provide an environmentally suitable alternative to the generally hazardous broad-spectrum chemical insecticides.

These bacterial insecticides like Nuclear Polyhedrosis Virus (NPV), which is target specific and exert no effect on beneficial organisms (e.g. parasitoids and predators). With the development of more effective *Bt* strains and improved commercial formulations, these insect pathogens are gaining increasing international support for use against agricultural insect pests. Most natural populations of *H. armigera* have at least some degree of infection by species-specific NPVs. When the degree of NPV infection can be enhanced then the *H. armigera* larval population can be decimated, without deleterious effects on any other organisms. Various potentially effective parasitoids, like ichneumonid, *Campoletis chloridae* and *Trichogramma* spp., are found parasitizing eggs and larvae of *H. armigera* infesting chickpea. Various insectivorous birds have long been observed to be effective predators of *H. armigera* larvae. Insectivorous birds such as myna and drongo helps to reduce the number of caterpillars. Activity of these birds can be enhanced, and more birds attracted, by placing bird perches in chickpea fields. Similarly various plant extracts have shown insecticidal properties and can be used effectively on field crops. Use of different bio-agents and botanicals having easy ways of formulation, cost effective, environmentally suitable and no or minimal deleterious effect on non target organisms, worthy of inclusion in most IPM packages. So, the biological control can be alternate system, which may play an important role in achieving the goal of agriculture.

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