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REVIEW

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The cotton bollworm (*Helicoverpa armigera*) and Azuki bean beetle (*Callosobruchus chinensis*): major chickpea (*Cicer arietinum* L.) production challenges on smallholder farmers in Ethiopia

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Abstract

Background: Chickpea (*Cicer arietinum* L.) is one of the most principally important legume crops in Ethiopia. Its production is mainly constrained by insect pests. Dissemination of updated information on its status and addressing alternative management options are important.

Main body: This article reviews the research status of the cotton bollworm (*Helicoverpa armigera*) and Azuki bean beetle (*Callosobruchus chinensis*) in chickpea, focusing on their distributions, host range, nature of the damage, biology, and their management practices. *Helicoverpa armigera* under field conditions and *C. chinensis* during storage are the most challenging insect pests of chickpea production in Ethiopia.

Conclusion: Managements of these two major insect pests are achieved through the use of cultural control, host plant resistance, botanical control, biological control, and chemical insecticides. Future research should focus on low-input IPM approaches that encompass all locally available and use of affordable insect pest management methods in Ethiopia.

Keywords: IPM, Host plant resistance, Botanical control, Biological control

Background

Chickpea (*Cicer arietinum* L.) is the most important grain legume in the world after common bean (*Phaseolus vulgaris* L.) and pea (*Pisum sativum* L.) (FAOSTAT, 2019). The seeds are a nutritious and rich source of cheap protein for the rapidly increasing population (Tejera et al., 2006). It has a dual purpose as human food and animal feeds, and also improves soil fertility through fixing the atmospheric nitrogen (Fikre et al., 2020; Werner, 2005). The crop is adapted to black soils in the cool semi-arid areas of the tropics, sub-tropics as well as temperate areas (Menale et al., 2009). It is grown all over the world in about 57 countries under varied environmental conditions including the Mediterranean basin, the Near East, Central, and South Asia, East Africa, South America, North America, and, more recently, in Australia. About 95% of chickpea cultivation and consumption is in developing countries and it contributes to around 46% of the total production of chickpea in Africa (Menale et al., 2009). African leading producers are Ethiopia, Tanzania, and Kenya (Mulwa et al., 2010; David, 2016; Mohamed et al., 2015). It ranks third in area coverage among pulses grown in Ethiopia that is preceded only by faba beans

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and haricot beans, generating revenue for the country and diversifying the cropping system (Fikre et al., 2020). Ethiopia is the largest producer, consumer, and exporter of chickpea in Africa and shares 4.5% of the global chickpea market and more than 60% of Africa's chickpea market (Tebkew & Ojiewo, 2017). Furthermore, the crop was among the major export commodities (Bejiga & Daba, 2006; Shiferaw & Teklewolde, 2007). In Ethiopia, it is widely grown across the highlands and semi-arid regions of the country (Bejiga et al., 1996; Dadi et al., 2005). The largest growing regions in Ethiopia are Oromiya and Amhara regions (Tebkew & Ojiewo, 2017). The national average yield of chickpea in Ethiopia is 1913 kg/ha which remains below the potential of the crop (Keneni et al., 2011). Furthermore, disproportionally, the potential of the crop under improved management condition is more than 3 tons per hectare (Dadi et al., 2005) and also it's below the world chickpea production average 5 tones/ha. In Ethiopia, chickpea production was limited due to both biotic and abiotic factors. Biotic factors such as diseases; root diseases (fusarium wilt, collar rot, and dry root rot), and foliar diseases (Ascochyta blight, Botrytis grey mold) (Tadesse et al., 2017; Getaneh et al., 2021), and insect pests mainly *Helicoverpa armigera* Hübner (Lepidoptera: Noctuidae) and *Callosobruchus chinensis* (L.) (Coleoptera: Bruchidae) (Damte & Mitiku, 2021; Fite et al., 2018). The later two insect pests were among the major factors affecting chickpea production in Ethiopia (Damte & Mitiku, 2020; Fite et al., 2019). *Helicoverpa armigera* causes up to 33% pod damage at field (Tebkew, 2004) and *C. chinensis* can causes up to 50% weight losses in Ethiopia (Tebkew & Mohamed, 2006). Due to the scarcity of comprehensive published information on *H. armigera* and *C. chinensis* in chickpea and their management practices at the African level, we focused more on an Ethiopian level, since the country is one of the top African chickpea producers and consumers. In Ethiopia, *H. armigera* and *C. chinensis* are the most major insect pests of chickpea at field and storage conditions, respectively. Hence, the objective of this article is to review *H. armigera* and *C. chinensis* and their management practices in chickpea.

Cotton bollworm, *Helicoverpa armigera* Hübner (Lepidoptera: Noctuidae)

Distribution and extent of damage

Helicoverpa armigera is a cosmopolitan pest of high mobility, and migratory potential (Forrester et al., 1993; Wakil et al., 2010). *Helicoverpa armigera* was considered the most prevalent insect pest of chickpea in Ethiopia (Fite et al., 2019; Mihretie et al., 2020) and throughout Africa, Europe, Australia, the Middle East, New Zealands, and the Pacific Islands (Sharma, 2005). It was also the most prevalent in the field on chickpea in Kenya (Kimurto et al., 2004), Tanzania (Maerere et al., 2010) and Sudan (Mansour & Mohmoud, 2014) from early seedling to maturity. *Helicoverpa armigera* was detected in all chickpea and other host-growing areas in Ethiopia.

The immature stages (1st, 2nd, and 3rd instar larvae) initially feed on the young shoot leaves of chickpeas. Occasionally, they enter the pod and feed upon the developing grains, and shift to developing seeds and fruits as larval instar development progresses (Reed & Pawar, 1982). The extent of pod damage on chickpea by this insect pest was found to vary with altitude; indicating that the insect was more important in mid-altitude areas than with low or high altitude chickpea growing zones (Tebkew, 2004). In chickpea, it causes up to 33% pod damage in Ethiopia (Tebkew, 2004) and 70–95% in India (Prakash et al., 2007).

Biology and seasonal abundance of *H. armigera*

The eggs of *H. armigera* were laid singly during nighttime due to the moths' nocturnal behaviour. Freshly laid eggs are yellowish-white and glistering at first, later changed to dark brown before hatching (Ali et al., 2009). The larvae emerge after 3.37 ± 0.09 days of egg incubation. The first and second larval instars are yellowish-white to reddish-brown to blackhead capsules (Ali et al., 2009). Whereas, fully grown larvae are straw-yellow to green, pink, or light brown to reddish-brown with lateral brown strips, and the head, as well as prothoracic legs, are dark brown to black (Cunningham et al., 1999; Zalucki et al., 1994). Pupae are the obtect type with mahogany-brown colour up to 19 mm in length, smooth and rounded both anteriorly and posteriorly. They took about 10–14 days before becoming adults emerging of the adult moth depending upon the temperature (Ali et al., 2009; Nasreen & Mustafa, 2000). According to Fite et al. (2020a, 2020b), the activity of *H. armigera* reached the first peak being June and February the second highest peak via funnel-botrack pheromone trap at Dandi district in Ethiopia. Two population peaks were recorded in Ethiopia (Fite et al., 2020a, 2020b; Seid & Tebkew, 2002). In Egypt, up to four population peaks were reported in cotton using light traps (Al-mezayyen & Ragab, 2014).

Host plants and nature of damage

Helicoverpa armigera is a polyphagous and voracious feeder of diverse plant species. Over 200 plant species including economically important crops such as; cotton (*Gossypium hirsutum*), sorghum (*Sorghum bicolor*), pigeonpea [*Cajanus cajan* (L.) Millspaugh], chickpea (*C. arietinum*), maize (*Zea mays*), soybean (*Glycine max*), tomato (*Lycopersicum esculentum*), pepper (*Capsicum annum*), bean (*Vicia faba*), peas (*Pisum sativum*), sunflower (*Helianthus annus*), niger (*Guizotia abyssinica*) seeds and many other horticultural crops were preferred by *H. armigera* (Fite et al., 2018; Tebkew, 2004; Waktole, 1996). The extent of damage depends on the type of host plants they fed upon. In chickpea, the eggs are laid on leaves and young pods. The larvae initially feed on the young leaves and the larger larvae bore into the pods and consume the developing seeds inside the pods. The insect destroys various plant parts like the pods, buds, flowers, and fruits of its host plants preferring, the harvestable part of economically important crops throughout the world (Sarwar, 2013).

Management strategies for *H. armigera*

Cultural control

Across Africa different cultural pest management have been employed for *H. armigera*. The use of manures, sowing dates, and plant density was also considered as a management part of *H. armigera* in Ethiopia (AdARC, 2002). Higher (3.3%) chickpea (*Worku* variety) pod damage was recorded at a plant density of 600/4.5m^2 indicating that increasing plant density will result in maximum pod damage, by favouring a higher *H. armigera* larval population. Early planted chickpea had a relatively greater number of larvae per plant than those sown late (DZARC, 1997). In other studies, early and late sown crops received higher *H. armiger* pod damage than mid sown chickpea (Hossain et al., 2008). Sanitation control measures like removing grass spp. from the nearby agricultural farms since cutworm prefers to live in moist and crack soils are the most important management part and considered as the cheapest of all methods (Tekeba, 2005).

Host plant resistance (HPR)

Host plant resistance presents an ideal means of combating notorious insect pests including *H. armigera* (Golla et al., 2018; Xiaoyi et al., 2015). Research has been conducted by East African scientists on screening chickpea genotypes for resistance and tolerance to *H. armigera* (Mansour & Mohmoud, 2014; Mulwa et al., 2010). There is evidence of HPR among chickpea genotypes in Ethiopia that showed some level of resistance to *H. armigera* under open field conditions. From a total of 78 chickpea genotype tested under field condition, genotypes such as; *ICCL-981/83-DZ/2-1, ICCL-7958/83-DZ/1-1, ICC-7881/82-DZ/4,* and *ICC-84204* and the improved variety *Marye* suffered only 1% pod damage, whereas, 22.02% from *ILC-2876* chickpea genotype (AdARC, 2002). Several germplasm accessions (*ICC 2580, ICC 7272, ICCV 92311, ICC 3362, ICCV 95311, ICC 506, EC 583311*, and *ICCVX 906183-1*) (Mulwa et al., 2010) and *EC58318, ICCV10, ICC14831, EC583260, EC583264*, and *EC583250* (Ruttoh et al., 2013) with tolerance to *H. armigera* have been identified in Kenya. In Sudan, genotypes *Atmore* and *Flip03-139c* recorded a higher level of resistance against *H. armigera* than the *Mattama, Hawata, Selwa, Wad Hamed, Jebel Marra, Flip03-127c* and *Flip04-9c* genotypes, which showed moderate resistance to *H. armiger* (Mansour & Mohmoud, 2014). Farmers believe that use of local landrace chickpea varieties; mainly Desi type chickpea varieties are more moderately resistant to *H. armigera* than the Kabuli types (Fite et al., 2019). Genotypes resistant to *H. armigera* accumulated more oxalic acid (in leaf exudate as an antibiotic factor) on the leaves and growth inhibition on *H. armigera* larvae when included in a semi-artificial diet (Mitsuru et al., 1995). Although a promising level of HPR to *H. armigera* has been found, the mechanism of resistance has not been adequately addressed on chickpea.

Biological control of *H. armigera*

Biological control by natural enemies and microbes are an important component of IPM programs against plant pests (Barratt et al., 2018; Van Lenteren et al., 2018) including *H. armigera* (Seid & Tebkew, 2002; Crowder et al., 2010; Fite et al., 2020a, 2020b).

Parasitoids and predators

Natural enemies, mainly the parasitoids, play a crucial role in the population regulation of *H. armigera*. More than 176 parasitoid species have been reported on *H. armigera* associated with different host plants in Africa so far (Van den Berg, 1993). In the cotton field, some egg parasitoids were recorded in Ethiopia such as; *Trichogramma* spp. and *Telenomus* spp. (IAR, 1985). Several egg and larval parasitoids *H. armigera* have been reported from Ethiopia (Table 1). For instance, about 12% of the *H. armigera* eggs were found parasitized by egg parasitoids (Trichogrammatidae, *Trichogramma* spp. and Scelionidae, *Telenomus* spp.) (Alemayehu et al., 2002) in Ethiopia. Similarly, egg parasitism by native Trichogrammatids on chickpea was reported by Gangaraddi (1987), who found 4% of *H. armigera* eggs parasitized by *Trichogramma achaeae* Nagaraja and Nagarkatti in India. Previously, larval and egg parasitoids such as; Tachinids, Ichneumonid wasps (*Charops* sp.), and egg parasitoids (*Trichogramma* sp.) have been described on *H. armigera* in Ethiopia (Seid & Tebkew, 2002). More recently, Fite et al. (2021) identified four tachinids; *Drino* sp. (Fig. 1A), *Goniophthalmus halli* (Fig. 1B), *Linnaemya cf. longirostris* (Fig. 1C), *Pimelimyia* sp. (Fig. 1D), and one ichneumonid (Fig. 1E) species; *Charops* sp. as larval parasitoids of *H. armigera* in chickpea from Ethiopia (Table 1). *Drino* sp. was the most predominant and common larval parasitoid species found in most of the surveyed districts with a parasitism rate ranging from 5.9% in Aqaqi to 13% in

Table 1 Natural enemies of *H. armigera* in Ethiopia

Bio-agents	Species/genus	Order: family	Host stage parasitized	Efficacy level	Crop/host	Geographical location	References
Parasitoids	*Trichogramma spp.*	Hymenoptera: Trichogrammatidae	Egg	12%	Cotton	Ethiopia	Alemayehu et al. (2002)
	Telenomus spp.	Hymenoptera: Scelionidae				Ethiopia	Alemayehu et al. (2002)
	Apanteles spp.	Hymenoptera: Braconidae	Larval	61.1%	Cotton	Ethiopia	Alemayehu et al. (2002)
	–	Hymenoptera: Ichneumonidae	Larval	29.9%	Cotton	Ethiopia	Alemayehu et al. (2002)
	–	Hymenoptera: Ichneumonidae	Larval	5–10%	Different crops	Ethiopia	Seid and Tebkew (2002)
	–	Diptera: Tachinidae	Larval	10%		Ethiopia	Alemayehu et al. (2002)
	Drino sp.	Diptera: Tachinidae	Larval	8.1%	Chickpea	Ethiopia	Fite et al. (2021)
	Goniophthalmus halli	Diptera: Tachinidae	Larval	7.1%	Chickpea	Ethiopia	Fite et al. (2021)
	Linnaemya cf. longirostris	Diptera: Tachinidae	Larval	6.4%	Chickpea	Ethiopia	Fite et al. (2021)
	Pimelimyia sp	Diptera: Tachinidae	Larval	5.46%	Chickpea	Ethiopia	Fite et al. (2021)
	Charops sp.	Hymenoptera: Ichneumonidae	Larval	6%	Chickpea	Ethiopia	Fite et al. (2021)
Predators	Bugs, ladybird beetles, and some spiders	–	–	–	–	Ethiopia	EARO (2000)
	Tiphia sp.	Hymenoptera: Tiphiidae	–	–	–	Ethiopia	Abate (1991)

Tokke Kutaye districts (Fite et al., 2021). Ichneumonid wasps were recorded causing 5–10% larval mortality to *H. armigera* at Wello, Northern Ethiopia (Seid & Tebkew, 2002). Similarly, in cotton, *Charops* sp. was also detected in striga (Milner, 1967) in Tanzania. Nyambo (1990) recorded *Charops* sp. from *H. armigera* larvae collected from tomato, cleome, and chickpeas. Predators such as; bugs, ladybird beetles, and some spiders (EARO, 2000) and the wasp (*Tiphia* sp.) have been recorded in Ethiopia as a predatory on *H. armigera* larvae (Abate, 1991).

Microbial pesticides

Some of the microbes effective for the control of *H. armigera* larvae have included bacteria; *Bacillus thuringiensis* (*Bt.*) (Das et al., 2016), viruses; nuclear polyhedrosis virus (NPV) (Gómez Valderrama et al., 2018), and entomopathogenic fungi (Fite et al., 2019). *Bacillus thuringiensis* is available as a selective spray that only kills moth larvae and the pathogen is extensively studied on various caterpillars including *H. armigera* larvae (Das et al., 2016; Silva et al., 2018; Fite et al., 2019). *Bacillus thuringiensis* Berliner variety *kurstaki* were effective at the rate of 1.50 kg/ha was successfully controlled the first and second instar larvae of *H. armigera* up to an average of 99.58 and 90.42%, respectively (Alemayehu et al., 1993). *Bacillus thuringiensis* can also induce sublethal effects on the growth and reproduction of *H. armigera* (Fite et al., 2019). *Helicoverpa armigera* larvae were reported to be extremely prone to Bt δ-endotoxins (Avilla et al., 2005; Li & Bouwer, 2012). Entomopathogenic fungi/EPF; mainly strains of *B. bassiana* and *M. anisopliae* have been reported to be effective against *H. armigera* (Jarrahi & Safavi, 2016; Kalvnadi et al., 2018). These two EPFs are the most widely used and known for causing adverse effects on the biological parameters of *H. armigera* (Jarrahi & Safavi, 2016). Recently, Fite et al. (2019) tested native *B. bassiana* and *M. anisopliae* against larvae of *H. armigera* and found *B. bassiana* (Isolate; *APPRC-9604*) was very effective in causing high larval mortality and reduced pod damage under field conditions in Ethiopia. Similarly, Bajya et al. (2015) had reported, *B. bassiana* was highly effective in controlling *H. armigera* populations in chickpea after two sprays under field conditions.

Population monitoring

Pheromone traps are described as a good tool to monitor lepidopterous pests (Malik & Ali, 2002). Monitoring of *H. armigera* by using pheromone traps or light traps was successfully implemented and incorporated as basic tools used to monitor, forecast, prediction, and control decisions based upon the populations of the moth catch (Fite et al., 2020a, 2020b; Kemal & Tibebu, 1994; Yenumula & Prabhakar, 2012). Kemal and Tibebu (1994) reported that the seasonal activity, abundance, and the damages

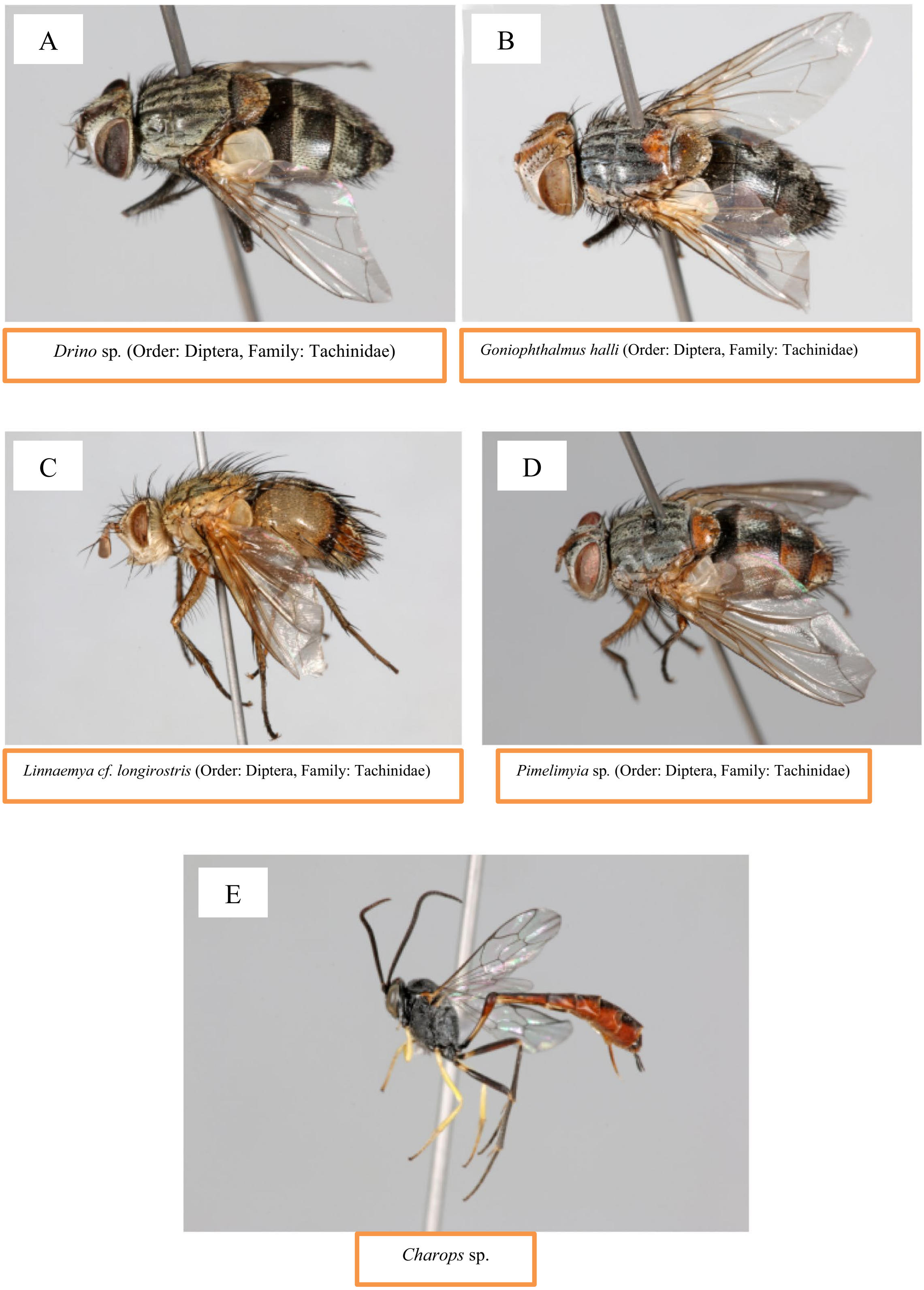

Fig. 1 Larval parasitoid of *H. armigera* (*Sources*: Fite et al., 2019)

inflicted by *H. armigera* to pulse crops are greatly differing from place to place in Ethiopia. Using pheromone and light traps he found that the number of moth catch was low from January to April and the increment of the catch from the first week of May reaching the peak in June and July when the wind speeds were 1.94 m/s with high temperature. Fite et al. (2020a, 2020b) evaluated commercial traps and lures and found that funnel trap with botrack was most effective in couching *H. armigera* moths and specific at the agro-ecological area of Dandi district, Oromiya, Ethiopia during 2018/2019. Two population peaks of *H. armigera* were reported under the agro-ecology of Dandi district, Oromiya, Ethiopia (Fite et al., 2020a, 2020b). The economic threshold for chickpea is to treat if more than 5 moths/trap/night are capture (Reena et al., 2009).

Botanical pesticides

Botanical pesticides are now emerging as a promising insect pest management strategy on all crops due to their safety to natural enemies, the environment, and humans, and being cost-effective compared to synthetic pesticides (Junhirun et al., 2018; Begg et al., 2017; Fite et al., 2020a, 2020b). *Azadirachta indica* A. Juss and *Milletia ferruginea* have been used as a component of IPM (Habeeb, 2010; Hussain et al., 2015; Mulatu, 2007). Aqueous extracts of *A. indica* and *M. ferruginea* seed-powder at 5% concentration highly reduced larval infestations and pod damage due to *H. armigera* under field conditions in Ethiopia (Fite et al., 2020a, 2020b). Besides, direct larval mortality; aqueous extracts of *A. indica* and *M. ferruginea*, and 50% oil extracts of *A. indica* have deterrent effects against *H. armigera* egg lying under laboratory conditions (Fite et al., 2018). The extracts of *A. indica* from different parts also influenced negatively both the survival and feeding of the larvae of *H. armigera* under laboratory experiments (Mesfin et al., 2012). Still, exploitation of other native botanical pesticides and their active ingredients and mode of actions remained in most cases.

Synthetic chemicals

The indiscriminate and misuse of synthetic insecticides can lead to environmental pollution, health hazards to humans and other animals, resistance development, disruption of non-target insects, pest resurgence, and many other side effects (Aboua et al., 2010; Mollaei et al., 2011). However, in the IPM system, chemical pest management is considered as the last resort that should be a need-based schedule application. Synthetic insecticides such as endosulfan, profenofos and lambdacyhalothrin have been frequently used for the control of *H. armigera* in the cotton field (Geremew & Surachate, 2005). Under field trials, a single application of cypermethrin 20% (Ripcord 20%) or cypermethrin 25% (Cymbush 25%) at peak flowering of chickpea gave the least pod damage due to *H. armigera* (DZARC, 1997). Similarly, a single application of cypermethrin or endosulfan at peak flowering of chickpea was found effective in controlling *H. armigera* and reduced pod damage compared to the applications at peak flowering and mid-pod setting stages (Kemal & Tibebu, 1994). Conventional broad-spectrum insecticide products are not compatible with IPM programs, such as advanced generation pyrethroids and organophosphates (Deshmukh et al., 2010; DZARC, 1997; Kemal & Tibebu, 1994) have been used against *H. armigera*.

Insecticide resistance and integrated management for *H. armigera*

The indiscriminate use of synthetic insecticides has led to several adverse effects including resistance developments in *H. argimera*. Hence, due to its economic importance, insecticides are frequently used for the controlling of *H. argimera* which has been developed resistance to several conventional insecticides from the organophosphate, pyrethroid, and carbamate groups. Moreover, these insecticides are harmful to beneficial insects, thus it has become important to use insecticides that are ecologically safe for natural enemies. For instance, chemical group of insecticides such as spinosad (chemical group: Spinosyn) and indoxacarb is safe to the natural enemies (Nasreen et al., 2003; Williams et al., 2003). Spinosad was reported to be very effective against the larvae of *H. argimera* both on contact and by ingestion (Carneiro et al., 2014; Hamed & Khan, 2003). Recently, the application of Indoxacarb (Avaunt 150 SC) at 0.3 Lha^{-1} or Spinosad (Tracer 480 SC) at 0.15 Lha^{-1} three times with a week interval were reported to be effective in reducing the percentage of pod damage, mean larvae per plant and as a result increased grain yield ha^{-1} under field condition and can be advised for the management of *H.armigera* (Mihretie et al., 2020). However, still investigations for very soft and effective chemical group of insecticides are remained as research outlook. Therefore, these insecticides can be used in the Integrated Pest Management (IPM) program for the control of *H. armigera.* Nowadays, IPM is being used to find ecologically sound, economically viable, and environmentally safe ways of pest management and received better attention. Single pest management could not provide sustainable and effective control; therefore all the available options have to be incorporated together whenever they are compatible. For instance, by integrating neem, *Helicoverpa Nuclear Polyhedrosis Virus* (*HaNPV*) and endosulfan resulted in reducing damaged pods, achieved the highest grain yield in chickpea (Visalakshmi et al., 2005). In another study conducted by Kumari et al. (2015) a combination of pheromone trap, *Bt* and *HaNPV* were significantly reduced damaged pods. Further, research should focus on IPM of all major pests emphasizing economically important crops.

Adzuki bean beetle, *Callosobruchus chinensis* (L.), (Coleoptera: Chysomelidae (formerly Bruchidae))

Distribution and extent of damage

Callosobruchus chinensis is considered the most important cosmopolitan species of storage insects in many food legumes (Tsedeke & Orr, 2012) including chickpea in Ethiopia (Tebkew & Mohamed, 2006; Keneni et al., 2011). This insect was native to East Asia, where its major natural hosts are Phaseoleae (Tuda et al., 2004, 2005). It is a major storage insect pest of cultivated pulses mainly in low and mid-altitude (1500–2200 m a.s.l.) areas of Ethiopia (Tebkew & Mohamed, 2006). The insect causes significant quantitative and qualitative damage and loss to chickpea in Ethiopia (Damte & Mitiku, 2020; Kemal & Tibebu, 1994). Infests legumes in the field and damage stored chickpea that can cause up to 50% weight losses in Ethiopia (Tebkew & Mohamed, 2006) and 28% in Eritrea (Adugna, 2006). As for the storage of insect pests of chickpea in Ethiopia, it is a key challenge for farmers due to the absence of well-equipped storage technologies. Therefore, future research interventions should have to focus on postharvest storage technologies.

Biology of *C. chinensis*

The eggs of *C. chinensis* are laid on chickpea seeds and the larvae and pupae complete their development inside the grain. After hatching, the larvae bore into cotyledons where it develops into adults within a month then immediately they begin mating and oviposition (Yanagi et al., 2013). A single female may lay 100 eggs depending on the environmental condition (Gwinner et al., 1996). For instance, under Ethiopian conditions a single female lays an average of 65 eggs in her lifetime and a generation is completed in about 25 days under optimum conditions (Damte et al., 2018).

Host plants and nature of damage

Callosobruchus chinensis is one of the major, polyphogous pulse beetles, causing a considerable loss to grain legumes in storage. The larvae of *C. chinensis* are a major pest of stored of chickpeas and cowpeas (*Vigna unguiculata* L.) (Pandey & Singh, 1997), soybean (*Glycine max* L. Merrill; Wang et al., 2010), kidney bean (*Phaseolus vulgaris* L.; Li & Zhu, 2009), pigeonpea (*Cajanus cajan* (L.) Millspaugh; Nahdy et al., 1998), peanut (*Arachis hypogaea* L.; Li & Zhu, 2009), lentils (*Lens cultinaris* Medik; Srinivasacharyulu & Yadav, 1997), adzuki bean (*Vigna angular* Ohwi & Ohashi; Tomooka et al., 2000), cowpea (*Vigna unguiculata* L.; Tomooka et al., 2000), faba bean (*Vicia faba* L.; Podoler & Applebaltm, 1968) and field pea (*Pisum sativum* L.; Bhagwat et al., 1995) across various geographical regions. In addition to the actual losses inflicted, the grain loses its germinating capacity (Ahmed & Din, 2009; Kumar et al., 2009) and nutritional quality (Sharma et al., 2007) once attacked by the beetles. It is the larvae that feed and damage the seeds. The damage and yield loss caused by *C. chinensis* depend upon the condition of the environments, for instance, the higher temperature and relative humidity that is conducive for the growth and development of pests (Singh, 2002). The adult and grub *C. chinensis* feed by making a small hole on chickpea seeds.

Management strategies for *C. chinensis*

Cultural control

Currently, various management options have been employed under smallholder conditions to reduce the damage caused by *C. chinensis*. To protect stored grains from insect pests farmers in Ethiopia uses; periodic winnowing, proper sun-drying before storage and at intervals, mixing plant materials with stored grains, mixing with inert materials (wood ash and sand), and mixing small grains with larger grains (Boxall, 1998), for instance admixing grain with teff (*Eragrostis teff*) are some of the most important cultural practices in IPM (Adugna, 2015; Damte & Mitiku, 2021). However, recently, the effectiveness of mixing chickpea with teff against *C. chinensis* was questionable (Damte & Mitiku, 2021).

Host plant resistance (HPR)

Breeding of productive genotypes with better genetic resistance to storage insect pests could be one of the stable alternatives to address problems of both developed and developing countries (Tebkew & Mohamed, 2006). The importance of host genetic improvement for resistance in chickpea for storage insect pests was also highlighted (Eker et al., 2018; Keneni et al., 2011; Swamy et al., 2020). Recently, it was evident that high protein and low starch content in maize seed were related to the resistance of maize to maize weevil (*Sitophilus zeamais* (Motschulsky) (Egas et al., 2017). Likely, some chickpea accessions such as Acc. Nos. *41320, 41289, 41291, 41134, 41315, 207658, 41103, 41168, 41142, 41174, 41029, 41207, 209087, 231327, 41161* and *41008* were found to have relatively better levels of resistance to *C. chinensis* in Ethiopia (Keneni et al., 2011). Suggesting that, resistant varieties can be used as gene sources in breeding new cultivars resistant to *C. chinensis*.

Biological control of *C. chinensis*

Natural enemies

Mainly two of the parasitoids; *Anisopteromalus calandrae* Howard and *Dinarmus basalis* Rondani (both Hymenoptera: Pteromalidae) were the major natural enemies of *C. chinensis* found in chickpea–teff mixture and together they caused up to 98% larval parasitism in grains of Arerti (kabuli type) and 56% in Natoli (desi type) (Damte & Mitiku, 2021). Both *A. calandrae* and *D. basalis* are dominant and cosmopolitan larval and pupal parasitoids of *C. chinensis* that develop concealed within the host substrate (Ghimire & Phillips, 2007; Niedermayer et al., 2016). These two parasitoids were recently reported from Ethiopia, and detailed research remained for the future. Moreover, *A. calandrae* and *Lariophagus distinguendus* (Hymenoptera: Pteromalidae) were reported to be effective at reducing the *C. chinensis* larval population, causing above 90% mortality rates in controlled conditions (28 ± 2 °C, 75 ± 5% relative humidity [RH]) (Iturralde-García et al., 2020). Therefore, these parasitoids can be used as effective biological control agents for the management of *C. chinensis* in stored chickpea as an alternative to the applications of liquid and gaseous insecticides.

Botanical pesticides

Botanical pesticides have been used as grain protectants (Park et al., 2016). Combination of ash (at 1:1 ratio, chickpea seeds to ash), insecticide (malathox 1% at 15 ppm), and oil (sesame oil at 10 mL kg^{-1}) were found effective in controlling *C. chinensis* for up to two months without severing grain damage to chickpea seeds (Adugna, 2015). Botanicals proved as a promising, locally available, socially acceptable, environmentally-friendly, and effective for the management of *C. chinensis* in chickpea and can be used as a component of IPM (Alemayehu & Getu, 2015). Mustard oil at 10 ml oil/kg of chickpea seed as a protectant was effective for up to five months against *C. chinensis* (Feeroza et al., 2008); botanicals such as *M. ferruginea*, *Datura stamonium*, *A. indica*, and *Chenopodium ambrosioides*, inert materials (wood ash and sand) and edible seed oils (*Brassica juncea*, *Linum usitatissimum* and *Guizotia abyssinica*) were very effective in controlling *C. chinensis* in stored chickpea grains (Tabu et al., 2012). Seed powder of *A. indica* at the rate of 20 g kg^{-1} (Tebikew & Mekasha, 2002), at 2–3% w/w (Teshome, 1990) caused high mortality, and *M. ferruginea* at 5% w/w and fermented tobacco provided gave complete protection of chickpea for a long period (Tebikew & Mekasha, 2002). Noug (*Guizotia abyssinica*) oil was also reported as effective as primiphosmethyl (Alemayehu & Getu, 2015). Seed powder of *A. indica* at the rate of 20 g kg^{-1} caused high adult mortality next to Malathion 5% dust at the rate of 0.5 g kg^{-1} (Tebikew & Mekasha, 2002). As previously known, environmental conditions favour insect pest population development throughout the year in stored products such as maize, thus the stored product must be monitored regularly and appropriate interventions implemented to avoid product loss (Danso et al., 2018) which is vital for time-based insecticide application if so required. Recently, an improved storage technology; the hermetic triple-bagging technology called PICS (Purdue Improved Crop Storage) (Baoua et al., 2015; Murdock & Baoua, 2014) was introduced to Ethiopia, but with slow dissemination due to lack of a straight ward extension system to millions of farmers. PICS bags were very effective in protecting cowpea grain against bruchids (Ibrahim et al., 2018).

Synthetic chemicals

Stored product insect control mainly depended on the application of liquid and gaseous insecticides (White & Leesch, 1995). Worldwide, malathion and fumigation with methyl bromide (Subramanyam & Hangstrum, 1995) and Actellic 2% dust (Pirimiphos-methyl) (Adenekan et al., 2013) have been used for stored products as effective in controlling storage pests in various crops including pulses. The insecticide Pirimiphos-methyl at the rate of 4–5 ppm gives effective control of bruchids on stored bean grains (Abate, 1985). However, the insecticidal residuals remained on the treated crops may cause adverse side-effects on the human health and other beneficial organisms. Therefore, developing very simple, attractive, cost effective/cheap, sustainable, socially, and environmentally acceptable pest management against both *H. armigera* and *C. chinensis* in chickpea has paramount significances in boosting the productivity for small holder farmers.

Conclusions

Production and productivity of chickpea in Ethiopia were constrained mainly by *H. armigera* and *C. chinensis*. The economic losses inflicted by a single insect pest couldn't be achieved through a single pest management method. Therefore, a comprehensive systems approach is needed to help the Ethiopian resource-poor small scale farmers whose livelihoods have been either directly or indirectly dependent upon agriculture. Various control measures such as; cultural, monitoring, botanical pesticides, the use of natural enemies, host plant resistance, synthetic chemicals, and IPM strategies have been suggested under this review. IPM encompasses all pest management techniques, that should consider farmers' economic gain/profit, environment, sustainability, effectiveness, holistic and systematic approach. Therefore, further research in Ethiopia are required to design and develop effective and sustainable *H. armigera* and *C. chinensis* management alternatives to increase the production and productivity of chickpeas for small-holder farmers.

Abbreviations

HaNPV: Helicoverpa nuclear polyhedrosis virus; NPV: Nuclear polyhedrosis virus; IPM: Integrated pest management; PICS: Purdue improved crop storage; HPR: Host plant resistance; EPF: Entomopathogenic fungi.

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References

Abate, T. (1985). Evaluation of some insecticides for the control of the bean bruchid, *Callosobruchus chinensis* (L.), on stored haricot bean. *Ethiopian Journal of Agricultural Science, 7*, 109–118.

Abate, T. (1991). Intercropping and weeding effects on some natural enemies of African bollworm *Heliothis armigera* (Hübn.) (Lepidoptera: Noctuidae) in bean fields. *Journal of Applied Entomology, 112*, 38–42.

Aboua, L. R., Seri-Kouassi, B. P., & Koua, H. K. (2010). Insecticidal activity of essential oils from three aromatic plants on *Callosobruchus maculatus* F. in Côte D'ivoire. *European Journal of Scientific Research, 39*(2), 243–250.

AdARC. (2002). Summary of research achievements (1987–2001). Adet Agricultural Research Centers (AdARC), Bahir Dar, Ethiopia.

Adenekan, M. O., Okpeze, V. E., Ogundipe, W. F., & Oguntade, M. I. (2013). Evaluation of *Moringa oleifera* powders for the control of bruchid beetles during storage. *International Journal of Agricultural Policy and Research, 1*(10), 305–310.

Adugna, H. (2006). On-farm storage studies on sorghum and chickpea in Eritrea. *African Journal of Biotechnology, 5*(17), 1537–1544.

Adugna, H. (2015). Eco-friendly management of chickpea storage pest, *Callosobruchus chinensis* L. (Coleoptera: Bruchidae) under laboratory conditions in Eritrea. *Journal of Stored Products and Postharvest Research, 6*(8), 66–71.

Ahmed, S., & Din, N. (2009). Leaf powders of basil (*Ocimum basilicum L.*), lantana (*Lantana camara* L.) and gardenia (*Gardenia jasminoides* Ellis) affect biology of *Callosobruchus chinensis* L. (Coleoptera: Bruchidae). *Journal of Pakistan Entomology, 31*, 5–9.

Alemayehu, M., & Getu, E. (2015). *Callosobruchus chinensis* (L.) (Coleoptera: Bruchidae) Management on stored chickpea using botanicals in Amhara region. *Ethiopia. American Journal of Experimental Agriculture, 8*(3), 167–177.

Alemayehu, R., Sithanantham, S., Baya, J., Matoka, C. M., Mohammed, D., & Mulugeta, N. (2002). Biological control of African bollworm, *Helicoverpa armigera*: Potential in Ethiopia in context of global scenario. African bollworm management in Ethiopia. Status and need. In *Proceedings of the national workshop held at the Ambo Plant Protection Research Center, Ambo, Ethiopia*.

Alemayehu, R., Tadesse, G. M., & Mengistu, H. (1993). Laboratory and field evaluations of *Bacillus thuringiensis* Berliner var. *kurstaki* on African bollworm, *Helicoverpa armigera* (Hübner). In *Proceeding of the first annual conference of crop protection society of Ethiopia, Addis Ababa, Ethiopia* (pp. 28).

Ali, A., Choudhury, R. A., Ahmad, Z., Rahman, F., Farmanur, R. K., Syed, K. A., & Ahmad, S. K. (2009). Some biological characteristics of *Helicoverpa armigera* on chickpea. *Tunisian Journal Plant Protection, 4*(1), 99–106.

Al-Mezayyen, G. A., & Ragab, M. G. (2014). Predicting the American bollworm, *Helicoverpa armigera* (Hübner) field generations as influenced by heat unit accumulation. *Egyptian Journal of Agricultural Research, 92*(1).

Avilla, C., Vargas-Osuna, E., González-Cabrera, J., Ferré, J., & González- Zamora, J. E. (2005). Toxicity of several delta-endotoxins of *Bacillus thuringiensis* against *Helicoverpa armigera* (Lepidoptera: Noctuidae) from Spain. *Journal of Invertebrate Pathology, 90*, 51–54.

Bajya, D. R., Ranjith, M., & Raza, S. K. (2015). Evaluation of *Beauveria bassiana* against chickpea pod borer, *Helicoverpa armigera* and its safety to natural enemies. *Indian Journal of Agricultural Science, 85*(3), 378–381.

Baoua, I. B., Amadou, L., Abdourahmane, M., Bakoye, O., Baributsa, D., & Murdock, L. L. (2015). Grain storage and insect pests of stored grain in rural Niger. *Journal of Stored Product Research, 64*, 8–12.

Barratt, B. I., Moran, V. C., Bigler, F., & van Lenteren, J. C. (2018). The status of biological control and recommendations for improving uptake for the future. *BioControl, 63*, 155–167.

Begg, G. S., Cook, S. M., Dye, R., Ferrante, M., Franck, P., Lavigne, C., & Lövei, G. L. (2017). A functional overview of conservation biological control. *Crop Protection, 97*, 145–158.

Bejiga, G., & Daba, K. (2006). Breeding chickpea for wide adaptation. In: Kemal et al (eds) *Food and forage legumes of Ethiopia progress and prospects, ICARDA, Addis Ababa, Ethiopia*. pp. 59–66.

Bejiga, G., Eshete, M., & Anbessa, Y. (1996). Improved cultivars and production technology of chickpea in Ethiopia. *Research Bulletin No. 2, Debre Zeit Agricultural Research Center, Debre Zeit, Ethiopia*. p. 60.

Bhagwat, V. R., Bodhade, S. N., Aherkar, A. K., & Narsinghan, V. G. (1995). Laboratory studies on the relative susceptibility of some pea (*Pisum sativum*) genotypes to pulse beetles, (*Callosobruchus chinensis* Linn). *Pestology, 19*, 24–27.

Boxall, R. (1998). *Grain post-harvest loss assessment in Ethiopia*. Final Report. Natural Resources Institute, The University of Greenwich. Report No. 2377.

Carneiro, E., Silva, L. B., Maggioni, K., dos Santos, V. B., Rodrigues, T. F., Reis, S. S., & Pavan, B. E. (2014). Evaluation of Insecticides Targeting Control of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae). *American Journal of Plant Sciences, 5*, 2823–2828.

Crowder, D. W., Northfield, T. D., Strand, M. R., & Snyder, W. E. (2010). Organic agriculture promotes even natural enemies and natural pest control. *Nature, 466*, 109–112.

Cunningham, J. P., Zalucki, M. P., & West, S. A. (1999). Learning in *Helicoverpa armigera* (Lepidoptera: Noctuidae): A new look at the behaviour and control of a polyphagous pest. *Bulletin Entomological Research, 89*, 201–207.

Dadi, L., Regasssa, S., Fikre, A., & Mitiku, D. (2005). *Adoption of chickpea varieties in the central highlands of Ethiopia. Research report 62. EARO* (Ethiopian Agricultural Research Organization), Addis Ababa, Ethiopia.

Damte, T., Ali, K., Tesfaye, A., & Chichaybelu, M. (2018). Progresses in insect pest management research in highland food legumes of Ethiopia. *Ethiopian Journal of Crop Science, 6*(3), 343–368.

Damte, T., & Mitiku, G. (2020). Pattern of egg distribution by Adzuki bean beetle, *Callosobruchus chinensis* (L.) (Coleoptera: Chysomelidae) in stored chickpea under natural infestation. *Journal of Stored Products Research, 88*, 101683.

Damte, T., & Mitiku, G. (2021). Evaluation of traditional method of stored product protection: Effect of mixing tef (*Eragrostis tef*) grains with stored chickpea on occurrence of Adzuki bean beetle (*Callosobruchus chinensis*) and its natural enemies. *International Journal of Pest Management*. https://doi.org/10.1080/09670874.2021.1918358

Danso, J. K., Osekre, E. A., Opit, G. P., Manu, N., Armstrong, P., Arthur, F. H., Campbell, J. F., Mbata, G., & McNeill, S. G. (2018). Post-harvest insect infestation and mycotoxin levels in maize markets in the Middle Belt of Ghana. *Journal of Stored Products Research, 77*, 9–15.

Das, A., Datta, S., Sujayanand, G. K., Kumar, M., Singh, A. K., Shukla, A. A., Ansari, J., Kumar, M., Faruqui, L., Thakur, Sh., Kumar, P. A., & Singh, N. P. (2016). Expression of chimeric *Bt* gene, *Cry1Aabc* in transgenic pigeon (cv. Asha) confers resistance to *Helicoverpa armigera* Hubner. *Plant Cell, Tissue and Organ Culture, 127*(3), 705–715.

David, K. (2016). *Pulses crops grown in Ethiopia, Kenya and United Republic of Tanzania for local and Export Market*. International Trade Centre, Eastern Africa Grain Council.

Deshmukh, S. G., Sureja, B. V., Jethva, D. M., & Chatar, V. P. (2010). Field efficacy of different insecticides against Helicoverpa armigera (Hubner) infesting chickpea. *Legume Research, 33*(4), 269–273.

DZARC. (1997). *Annaul research report for the period 1994/95*. Debre Zeit Agricultuural Research Center (DZARC), Debre Zeit, Ethiopia.

EARO. (2000). *Ethiopian Agricultural Research organization. Annual report 1998/99*. Addis Ababa, Ethiopia, p. 26.

Egas, Nh., Stephen, M., Linnet, G., Tadele, T., Miriam, K., & Eduardo, M. (2017). Resistance of selected Mozambican local and improved maize genotypes to maize weevil, *Sitophilus zeamais* (Motschulsky). *Journal of Stored Products Research, 73*, 115–124.

Eker, T., Fedai, E., Alper, A., Baris, I., Halil, G., Hilal, S. T., et al. (2018). Screening of chickpea accessions for resistance against the pulse beetle, *Callosobruchus chinensis* L. (Coleoptera: Bruchidae). *Journal of Stored Products Research, 76*, 51–57.

FAOSTAT (Food and Agriculture Organization). (2019). http://www.fao.org/faostat/en/#data/QC (Verified 9/25/19).

Feeroza, K., Khalique, A., Muhammad, A., Bashir, A. M., & Mohammad, R. M. (2008). Protection of stored chickpea, *Cicer arietinum* L. from attack of *Callosobruchus chinensis* L. (Coleoptera: Bruchidae). *Tropical Pest Management, 34*(3), 333–334.

Fikre, A., Desmae, H., & Ahmed, S. (2020). Tapping the economic potential of chickpea in Sub-Saharan Africa. *Agronomy, 10*, 1707.

Fite, T., Damte, T., Tefera, T., & Negeri, M. (2020a). Evaluation of commercial trap types and lures on the population dynamics of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) and its effects on non-targets insects. *Cogent Food and Agriculture, 6*, 1–1771116.

Fite, T., Damte, T., Tefera, T., & Negeri, M. (2021). Hymenopteran and dipteran larval parasitoid species of the cotton bollworm, *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) in chickpea growing districts of Ethiopia. *Biocontrol Science and Technology., 31*(5), 541–545.

Fite, T., Tefera, T., Negeri, M., & Damte, T. (2020b). Effect of *Azadirachta indica* and *Milletia ferruginea* extracts against *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) infestation management in chickpea. *Cogent Food & Agriculture*. https://doi.org/10.1080/23311932.2020.1712145

Fite, T., Tefera, T., Negeri, M., Damte, T., & Sori, W. (2018). Management of *Helicoverpa armigera* (Lepidoptera: Noctuidae) by nutritional indices and botanical extracts of *Millettia ferruginea* and *Azadirachta indica*. *Advances in Entomology, 6*, 235–255.

Fite, T., Tefera, T., Negeri, M., Damte, T., & Sori, W. (2019). Evaluation of *Beauveria bassiana*, *Metarhizium anisopliae*, and *Bacillus thuringiensis* for the management of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) under laboratory and field conditions. *Biocontrol Science and Technology, 30*(3), 278–295.

Forrester, N. W., Cahill, M., Bird, L. J., & Layland, J. K. (1993). Management of pyrethroid and endosulfan resistance in *Helicoverpa armigera* (Lepidoptera: Noctuidae) in Australia. *Bulletin of Entomological Research, 1*, 1–132.

Gangaraddi, L. L. (1987). Studies on natural enemies of *Heliothis armigera* (Hübner) infesting bengalgram (*Cicer arietinum* Linnaeus) with special reference to *Trichogramma achaeae* (Nagaraja and Nagarkatti). *Mysore Journal of Agricultural Sciences Supplement, 21*, 92–93.

Geremew, T., & Surachate, J. (2005). Susceptibility of African bollworm (*Helicoverpa armigera*) populations to synthetic insecticides in Ethiopia. *Pest Management Journal of Ethiopia, 9*, 29–37.

Getaneh, G., Tefera, T., Lemessa, F., Ahmed, S., Fite, T., & Villinger, J. (2021). Genetic diversity and population structure of *Didymella rabiei* affecting chickpea in Ethiopia. *Journal of Fungi, 7*, 820.

Ghimire, M. N., & Phillips, T. W. (2007). Suitability of five species of stored-product insects as host for development and reproduction of the parasitoid *Anisopteromalus calandrae* (Hymenoptera: Pteromalidae). *Journal of Economic Entomology, 100*(5), 1732–1739.

Golla, K., Rajasekhar, P., Sharma, S. P., Prasad, K. V., & Sharma, H. C. (2018). Antixenosis and antibiosis mechanisms of resistance to *Helicoverpa armigera* in wild relatives of chickpea, *Cicer Arietinum*. *Euphytica, 214*, 88.

Gómez Valderrama, J. A., Barrera, G., López-Ferber, M., Belaich, M., Ghiringhelli, P. D., & Villamizar, L. (2018). Potential of betabaculoviruses to control the tomato leafminer, *Tuta absoluta* (Meyrick). *Journal of Applied Entomology, 142*, 67–77.

Gwinner, J., Hamisch, R., & Muck, O. (1996). Manuel sur la manutention et la conservation des grains après récolte. [Manual handling and preservation of grain after harvest]. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Eschborn, Germany, p. 368.

Habeeb, S. M. (2010). Ethnoveterinary knowledge of crude plant extracts and its methods of application traditional and modern for tick control. *West African Applied Science Journal, 11*(9), 1047–1050.

Hamed, M., & Khan, R. A. (2003). Toxicity of six commercial insecticides against Cotton Bollworm, *Helicoverpa armigera* (HUB.). *The Nucleus, 40*, 137–139.

Hossain, A. M., Azizul, H. M., & Prodhana, M. Z. (2008). Incidence and damage severity of *Helicoverpa armigera* (Hübner) in chickpea (*Cicer Arietinum* L.). *Bangladesh J. Sci. Ind. Res, 44*(2), 221–224.

Hussain, D., Muhammad, S., Ghulam, G., & Muneer, A. (2015). Resistance in a field population of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae). *Journal of Entomological Science, 50*(2), 119–128.

IAR. (1985). *Institute of Agricultural Research, Crop protection department progress report for the period 1980/81–1982/83*. 38pp. Addis Ababa, Ethiopia.

Ibrahim, B. B., Ousmane, B., Laouali, A., Larry, L. M., & Dieudonne, B. (2018). Performance of PICS bags under extreme conditions in the Sahel zone of Niger. *Journal of Stored Products Research, 76*, 96–101.

Iturralde-García, R. D., Riudavets, J., & Castañé, C. (2020). Biological control of *Callosobruchus chinensis* (Coleoptera: Chrysomelidae) in stored chickpeas through the release of natural enemies. *Biological Control, 149*, 104322.

Jarrahi, A., & Safavi, S. A. (2016). Fitness costs to *Helicoverpa armigera* after exposure to sub-lethal concentrations of *Metarhizium anisopliae* sensu lato: Study on F1 generation. *Journal Invertebrate Pathology, 138*, 50–56.

Junhirun, P., Wanchai, P., Thitaree, Y., Torranis, R., Opender, K., & Vasakorn, B. (2018). The study of isolated alkane compounds and crude extracts from *Sphagneticola trilobata* (Asterales: Asteraceae) as a candidate botanical insecticide for lepidopteran larvae. *Journal of Economic Entomology, 111*(6), 2699–2705.

Kalvnadi, E., Mirmoayedi, A., Alizadeh, M., & Pourian, H. (2018). Sub-lethal concentrations of the entomopathogenic fungus, *Beauveria bassiana* increase fitness costs of *Helicoverpa armigera* (Lepidoptera: Noctuidae) offspring. *Journal of Invertebrate Pathology, 158*, 32–42.

Kemal, A., & Tibebu H. (1994). Research on insect pests of cool-season food legumes. In Tilaye, A., Bejiga, G., Saxena, M. C., & Solh M. B. (eds.) *Coolseason Food Legumes of Ethiopia. Proceeding of the first national cool-season food legumes review conference* (pp. 367–396),16–20 December 1993, Addis Ababa, Ethiopia. ICARDA/IAR. ICARDA, Syria.

Keneni, G., Endashaw, B., Emana, G., Muhammad, I., Kifle, D., & Fassil, A. (2011). Characterization of Ethiopian chickpea (*Cicer arietinum* L.) Germplasm accessions for response to infestation by Adzuki bean beetle (*Callosobruchus chinensis* L.) performance evaluation. *Ethiopian Journal of Agricultural Science, 21*, 41–65.

Kimurto, P. K., Towett, B. K, Ogolla, J. B., Kinyua, M. G., & Metto, K. (2004). Farmer participatory selection and improvement of chickpea (*Cicer arietinum* L.) production in the semi-arid highlands of Kenya. In *Proceedings of 4th* *legume science conference* (pp. 23–27) 14–18th November 2004, Durban South Africa.

Kumar, A., Shukla, R., Singh, P., Singh, A., & Dubeya, N. (2009). Use of essential oil from *Mentha Sarvensis* L. to control storage moulds and insects in stored chickpea. *Journal of Sciences of Food and Agriculture, 89*, 2643–2649.

Kumari, K., Anil, K., Saha, T., Goswami, T. N., & Singh, S. N. (2015). Bio intensive management of *Helicoverpa armigera* (Hübner) in chickpea. *Journal of Eco-Friendly Agriculture, 10*(1), 50–52.

Li, H., & Bouwer, G. (2012). Toxicity of *Bacillus thuringiensis* Cry proteins to *Helicoverpa armigera* (Lepidoptera: Noctuidae) in South Africa. *Journal of Invertebrate Pathology, 109*, 110–116.

Li, L. S., & Zhu, W. B. (2009). *Stored product entomology* (pp. 162–165). Chongqing Press.

Maerere, A. P., Sibuga, K. P., Bulali, J. E., Mwatawala, M. W., Kovach, J., Kyamanywa, S., Mtui, H. D., & Erbaugh, M. (2010). Deriving appropriate pest management technologies for smallholder tomato (Solanum lycopersicum Mill) growers: A case study of Morogoro, Tanzania. *Journal of Animal and Plant Science, 6*(3), 663–676.

Malik, M. F., & Ali, L. (2002). Monitoring and control of codling moth, *Cydia pomonella* (Lepidoptera: Tortricidae) by pheromone traps in Quetta, Pakistan. *Asian Journal of Plant Science, 1*, 201–202.

Mansour, A. E., & Mohmoud, M. E. (2014). Effects of sowing dates and sorghum varieties on the incidence of sorghum midge, *Stenodiplosis sorghicola* (Coq) at Abu-Naama, Sudan. Persian Gulf. *Crop Protection, 3*, 88–91.

Menale, K., Shiferaw, B., Asfaw, S., Abate, T., Muricho, G., Ferede, S., Eshete, M., & Assefa, K. (2009). Current situation and future outlooks of the chickpea sub-sector in Ethiopia. In *EIAR (Ethiopian Institute of Agricultural Research) and ICRISAT (International Crops Research Institute for the Semi-Arid)*.

Mesfin, W., Emana, G., & Geremew, T. (2012). Survival and feeding of African bollworm, *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) affected by neem, *Azadirachta indica* (A. Juss) extracts. *World Journal of Agricultural Science, 8*(3), 280–285.

Mihretie, A., Yimer, D., Wudu, E., & Kassaw, A. (2020). Efficacy of insecticides against African bollworm (*Helicoverpa armigera* Hubner) on chickpea (*Cicer arietinum*) in the lowlands of Wollo, Norteastern Ethiopia. *Cogent Food & Agriculture, 6*(1), 1833818.

Milner, J. E. (1967). Report on a survey of the natural enemies of *Striga* spp. (Scrophulariaceae) in East Africa. Unpublished Report of the Commonwealth Institute of Biological Control. p. 57.

Mitsuru, Y., Susan, E., Cowgil, L., & John, A. W. (1995). Mechanism of resistance to *Helicoverpa armigera* (Lepidoptera: Noctuidae) in chickpea: Role of Oxalic acid in leaf exudate as an antibiotic factor. *Journal of Economic Entomology, 88*(6), 1783–1786.

Mohamed, A. A., Tahir, S. A., & Elhashimi, M. A. (2015). Assessment of genetic variability and yield stability in chickpea (*Cicer arietinum* L.) cultivars in River Nile State, Sudan. *Journal of Plant Breeding and Crop Sciences, 7*(7), 219–224.

Mollaei, M., Izadi, H., Dashti, H., Azizi, M., & Ranjbar, K. R. (2011). Bioactivity of essential oil from *Satureja hortensis* (Laminaceae) against three stored-product insect species. *African Journal of Biotechnology, 10*(34), 6620–6627.

Mulatu, B. (2007). Contact bioassay of an endemic plant to Ethiopia on three aphid species. *Ethiopian Journal of Biological Science, 6*(1), 51–62.

Mulwa, R. M., Kimurto, P. K., & Towett, B. K. (2010). Evaluation and selection of drought and *H. armiger* (*Helicoverpa armigera*) tolerant chickpea genotypes for introduction in semi-arid areas of Kenya. In *Second RUFORUM biennial meeting* (pp. 1042–1048), 20–24 September 2010 Entebbe, Uganda.

Murdock, L. L., & Baoua, I. B. (2014). On Purdue, Improved Cowpea Storage (Murdock LL, Baoua IB. 2014. On Purdue, Improved Cowpea Storage (PICS) technology: Background, mode of action, prospects. *Journal of Stored Products Research, 58*, 3–11.

Nahdy, M. S., Ellis, R. H., Silim, S. N., & Smith, J. (1998). Field infestation of pigeonpea (*Cajanus cajan* (L.) Millsp.) by *Callosobruchus chinensis* (L.) in Uganda. *Journal of Stored Products Research, 34*, 207–216.

Nasreen, A., & Mustafa, G. (2000). Biology of *Helicoverpa armigera* (Hubner), reared in laboratory on natural diet. *Pakistan Journal of Biological Sciences, 3*(10), 1668–1669.

Nasreen, A., Mustafa, G., & Ashfaq, M. (2003). Selectivity of some insecticides to *Chrysoperla carnea*(Stephen) (Neuroptera: Chryopidae) in laboratory. *Pakistan Journal of Biological Sciences, 6*(6), 536–538.

Niedermayer, S., Pollmann, M., & Steidle, J. L. (2016). *Lariophagus distinguendus* (Hymenoptera: Pteromalidae) (Förster)-past, present, and future: The history of a biological control method using *L. distinguendus* against different storage pests. *Insects, 7*, 39.

Nyambo, B. T. (1990). Effect of natural enemies on the cotton bollworm, *Heliothis armigera* Hubner (Lepidoptera: Noctuidae) in Western Tanzania. *Tropical Pest Management, 36*, 50–58.

Pandey, N. K., & Singh, S. C. (1997). Observations on the biology of the pulse beetle *Callosobruchus chinensis* (Linn.) infesting stored pulses. *Uttar Pradesh Journal of Zoology, 17*(1), 38–42.

Park, Ch. G., Shin, E., & Kim, J. (2016). Insecticidal activities of essential oils, *Gaultheria fragrantissima* and *Illicium verum*, their components and analogs against *Callosobruchus chinensis* adults. *Journal of Asia-Pacific Entomology, 19*(2), 269–273.

Podoler, H., & Applebaltm, S. W. (1968). Physiological aspects of host specificity in the Bruchidae-V. Varietal differences in the resistance of *Vicia faba* L. to *Callosobruchus chinensis* L. *Journal of Stored Products Research, 4*, 9–11.

Prakash, M. R., Ram, U., & Tariq, A. (2007). Evaluation of chickpea (*Cicer arietinum* L.) germplasm for the resistance to gram pod borer, *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae). *Journal of Entomology Research, 31*, 215–218.

Reed, W. & Pawar, C. S. (1982). Heliothis: a global problem. In: Reed, W. & Kumble, V. (eds) Proceedings of International Workshop on Heliothis Management, 15–20 November 1981. ICRISAT, Patancheru. pp. 9–14.

Reena, S. K., Singh, B. K., & Jamwal, B. S. (2009). Management of *Helicoverpa armigera* (Hübner) by intercropping and monitoring through pheromone traps in chickpea. *Karnataka Journal of Agricultural Science, 22*(3), 524–526.

Ruttoh, E. K., Mulwa, R. M., Ngode, L., Gohole, L., Towett, B., Njogu, N., Silim, S., Rao, G. V., & Kimurto, P. K. (2013). Screening for host plant resistance to *Helicoverpa armigera* (Lepidoptera: Noctuidae) in selected chickpea (*Cicer arientinum* L.) genotypes in Kenya. *Egerton Journal of Science and Technology, 13*, 39–55.

Sarwar, M. (2013). Survey on screening resistance resources in some chickpea (*Cicer arietinum* L.) genotypes against gram pod borer *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) pest. *International Journal of Agricultural Science, 3*(3), 455–458.

Seid, A., & Tebkew D. (2002). African bollworm: A key pest in pulses production in Ethiopia: Status and Need. Proceedings of the National Workshop held at the Plant Protection Research Center Ambo, Ethiopia.

Sharma, H. C., Gowda, C. L., Stevenson, P. C., Ridsdill-Smith, T. J., Clement, S. L., Ranga-Rao, G. V., Romies, J., Miles, M., & Bouhssini, M. (2007). Host plant resistance and insect pest management in chickpea. In: Yadav, S. S., Redden, R., Chen, W., & Sharma, B. (Eds.), Chickpea breeding and management (pp. 520–537). CAB International, Wallingford.

Sharma, H. C. (2005). *Heliothis/Helicoverpa Management: Emerging trends and strategies for future research*. Oxford and IBH Publishing Co.

Shiferaw, B., & Teklewold, H. (2007). Structure and functioning of chickpea markets in Ethiopia: Evidence-based on analyses of value chains linking smallholders and markets. In *Improving Productivity and Market Success (IPMS) of Ethiopian Farmers Project Working Paper 6* (p. 63). ILRI (International Livestock Research Institute), Nairobi, Kenya.

Silva, I. F., Baldin, E. L., Specht, A., Sosagómez, D. R., Roque-Specht, V. R., Morando, R., & Paula-Moraes, S. V. (2018). Biotic potential and life table of *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) from three Brazilian regions. *Neotropical Entomology, 47*(3), 344–351.

Singh, B. D. (2002). *Plant breeding: Principles and methods*. Kalyani Publishers.

Srinivasacharyulu, B. S., & Yadav, T. D. (1997). Olfactory and ovipositional preference of two strains of *Callosobruchus chinensis*. *Indian Journal of Entomology, 59*(2), 193–197.

Subramanyam, B., & Hangstrum, D. W. (1995). Resistance measurement and management. In B. Subramanyam & D. W. Hangstrum (Eds.), *Integrated Management of insects in stored products*. Marcel Dekker.

Swamy, S. V., Raja, D. S., & Wesley, B. J. (2020). Susceptibility of stored chickpeas to bruchid infestation as influenced by physico-chemical traits of the grains. *Journal of Stored Products Research, 87*, 101583.

Tabu, D., Selvaraj, T., Singh, S. K., & Mulugeta, N. (2012). Management of Adzuki bean beetle (*Callosobruchus chinensis* L.) using some botanicals, inert materials and edible oils in stored chickpea. *Journal of Agricultural Technology, 8*(3), 881–902.
Tadesse, M., Turoop, L., & Chris, O. O. (2017). Survey of chickpea (*Cicer Arietinum* L.) ascochyta blight (*Ascochyta Rabiei* Pass.). *Disease Status in Production Regions of Ethiopia, 5*(1), 23–30.
Tebikew, D., & Mekasha, Ch. (2002). The efficacy of some botanicals in controlling Adzuki bean beetle, *C. chinensis*, in stored chickpea. *Tropical Science, 42*, 192–195.
Tebkew, D. (2004). Importance of *H. armiger* in chickpea in some chickpea growing regions of Ethiopia. *Pest Management Journal of Ethiopia, 8*, 105–110.
Tebkew, D., & Mohamed, D. (2006). Chickpea, lentil and grass pea insect pest research in Ethiopia: A review. P. 260–273. In Ali, K., Keneni, G., Ahmed, S., Malhotra, R., Beniwal, S., Makkouk, K., & Halila, M. H. (eds.) *Food and forage legumes of Ethiopia: Progress and prospects. Proceedings of a Workshop on Food and Forage Legumes* (pp. 22–26) Sept 2003, Addis Ababa, Ethiopia. ICARDA, Aleppo, Syria.
Tebkew, D., & Ojiewo, C. O. (2017). Incidence and within field dispersion pattern of pod borer, *Helicoverpa armigera* (Lepidoptera: Noctuidae) in chickpea in Ethiopia. *Archives of Phytopathology and Plant Protection, 50*, 17–18.
Tejera, N. A., Soussi, M., & Lluch, C. (2006). Physiological and nutritional indicators of tolerance to salinity in chickpea plants growing under symbiotic conditions. *Environmental and Experimental Botany, 58*, 17–24.
Tekeba, Y. (2005). Species Composition of cotton Bollworms (Lepidoptera: Noctuidae and Gelechidae) and their management using cotton genotype and planting date in Metema North Ethiopia. M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.
Teshome, L. (1990).The biology and control of the adzuki been beetle (*Callosobruchus chinensis* L.) on chickpea (*Cicer arietinum* L.). M.Sc Thesis, Alemaya University, Ethiopia.
Tomooka, N., Kashiwaba, K., Vaughan, D. A., Ishimoto, M., & Egawa, Y. (2000). The effectiveness of evaluating wild species: Searching for sources of resistance to bruchid beetles in the genus Vigna subgenus Ceratotropis. *Euphytica, 115*, 27–41.
Tsedeke, A., & Orr A. (2012). Research and development for tropical legumes: Towards a knowledge-based strategy. *J eSAT Agricul Rese,* 10.
Tuda, M., Chou, L. Y., Niyomdham, C., Buranapanichpan, S., & Tateishi, Y. (2005). Ecological factors associated with pest status in Callosobruchus (Coleoptera: Bruchidae): high host specificity of non-pests to Cajaninae (Fabaceae). *Journal of Stored Products Research, 41*, 31–45.
Tuda, M., Wasano, N., Kondo, N., Horng, S. B., Chou, L. Y., & Tateishi, Y. (2004). Habitatrelated mtDNA polymorphism in the stored-bean pest *Callosobruchus chinensis* (Coleoptera: Bruchidae). *Bulletin Entomological Research, 94*, 75–80.
Van den Berg, H. (1993). Natural control of *Helicoverpa armigera* in smallholder crops in East Africa. Ph.D. Thesis, Wageningen. 90-5485-107-4.
Van Lenteren, J. C., Bolckmans, K., Kohl, J., Ravensberg, W. J., & Urbaneja, A. (2018). Biological control using invertebrates and microorganisms: plenty of new opportunities. *BioControl, 63*, 39–59.
Visalakshmi, V., Ranga, G. V., & Arjuna, R. P. (2005). Integrated pest management strategy against *Helicoverpa armigera* in chickpea. *Indian Journal of Plant Protection, 33*(1), 17–22.
Wakil, W., Ghazanfar, M. U., Kwon, Y. J., Qayyum, M. A., & Nasir, F. (2010). Distribution of *Helicoverpa armigera* Hübner (Lepidoptera: Noctuidae) in tomato fields and its relationship to weather factors. *Entomological Research, 40*(6), 290–297.
Waktole, S. (1996). Managements of cotton insect pests in Ethiopia: A review. In *Proceedings of integrating biological control and host plant resistance*. Addis Ababa, Ethiopia CTA/IAR/IIBC (pp. 224–252).
Wang, Y., Talekar, N. S., Chen, B., Li, Z. Y., & Chen, Z. Q. (2010). Study on the influence of legume varieties on the growth and oviposition preference of *Callosobruchus chinensis* (L.). *Journal of Yunnan Agricultural University, 25*, 34–39.
Werner, D. (2005). Production and biological nitrogen fixation of tropical legumes. In D. Werner & W. E. Newton (Eds.), *Nitrogen fixation in agriculture, forestry, ecology, and the environment* (pp. 1–13). Springer.
White, N. D., & Leesch, J. G. (1995). Chemical control. In B. Subramanyam & D. W. Hagstrum (Eds.), *Integrated management of insects in stored products*. Marcel Dekker.
Williams, T., Valle, J., & Vinuela, E. (2003). Is the naturally derived insecticide Spinosad compatible with insect natural enemies? *Biocontrol Science and Technology, 13*(5), 459–475.
Xiaoyi, W., Haifeng, C., Aihua, S., Rong, Z., Zhihui, S., Xiaojuan, Z., et al. (2015). Laboratory testing and molecular analysis of the resistance of wild and cultivated soybeans to cotton bollworm, *Helicoverpa armigera* (Hübner). *The Crop Journal, 3*, 19–28.
Yanagi, S. I., Saeki, Y., & Tuda, M. (2013). Adaptive egg size plasticity for larval competition and its limits in the seed beetle *Callosobruchus chinensis*. *Entomological Experimental Application, 148*, 182–187.
Yenumula, P., & Prabhakar, M. (2012). Pest monitoring and forecasting. In U. Shankar & D. P. Abrol (Eds.), *Integrated pest management: Principles and practice* (pp. 41–57). Cabi: Oxford shire.
Zalucki, M. P., Murray, D. A., Gregg, P. C., Fitt, G. P., Twine, P. H., & Jones, C. (1994). Ecology of *Helicoverpa armigera* (Hübner) and *Helicoverpa punctigera* (Wallengren) in the inland of Australia: Larval sampling and host plant relationships during winter and spring. *Australian Journal of Zoology, 42*, 329–346.

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