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An Overview of the Biological Aspects, Nature of Damage and Strategies for Managing the Gram Pod Borer (*Helicoverpa armigera* Hubner) in Chickpea: A review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Gram pod borer, *Helicoverpa armigera*, a globally widespread and cosmopolitan insect pest, poses a significant threat to chickpea productivity worldwide. The effective management of this pest is paramount for ensuring sustainable chickpea yields. The life cycle of *H. armigera* spans approximately 4-5 weeks, progressing through egg, larvae, pupae and adult stages. During the initial 1st to 3rd instar larval phases, the insect primarily engages in feeding on leaves, twigs, and flowers. As the larvae advance to the 4th to 6th instar stages, they shift their focus to developing pods, creating holes or bores and consuming entire seeds. Yield losses of up to 90 percent may occur, contingent upon insect density and cultivar susceptibility. A comprehensive approach to sustainable chickpea pod borer management encompasses the utilization of resistant cultivars, strategic manipulation of sowing dates, maintaining optimal crop density, nutritional management, deployment of trap crops (such as maize, sunflower, sorghum, safflower, pigeon pea, okra and tomato), installation of animated bird perches and the application of biological control measures involving plant extracts, virus/bacteria-based insecticides and entomopathogenic nematodes. In instances of pod borer outbreaks, chemical insecticides are considered a last resort for farmers. However, the adoption of resistant cultivars, adherence to recommended cultural practices and the integration of biological control methods have proven to be more efficacious, economically viable, sustainable and environmentally friendly in the management of chickpea pod borer.

Keywords: Biological control; Chickpea; Helicoverpa armigera; insecticide; management; pod damage.

1. INTRODUCTION

Chickpea (*Cicer aritinum* L.) is the second most important pulse crop in the world and belongs to the family Leguminosae and subfamily Papilionaceae. It is a self-pollinated crop and is an important pulse crop grown in all parts of the world under different environmental conditions [1] and is world's third largest legume crop based on the cultivated area [2]. Chickpea is an important source of protein in human diets in many countries and plays a prominent role in the farming system. It has one of the highest nutritional compositions as of any dry edible legume and is not reported to contain any specific major anti-nutritional factors. Biotic stresses include diseases, insects, nematodes, birds and vertebrates causing damage to the crop. Among all stresses, insect damage is more pronounced than the other stresses. The most important pests of chickpea is gram pod borer, *H. armigera* which appears in vast numbers during vegetative and pod formation stages of chickpea [3] and is most common and critical challenge for chickpea productivity around the world [4,5]. “In case of outbreaks, yield losses caused by chickpea pod borer range from 10-90 percent depending upon the insect population and susceptibility of genotypes” [6]. “*H. armigera* is widely dispersed throughout the African, Asian, European and Mediterranean regions” [7-10]. “In Europe *H. armigera* is widespread chickpea pest while limited distribution of pest has been reported in Hungry, France, Italy and Cyprus” [11]. “Former reports on extent of damage by pod borer are evident that significant yield losses have been recorded in Southern Asia. Pod damage in unprotected chickpea crops were recorded up to 85 per cent in India, 90 per cent in Pakistan and 5-15 per cent in Bangladesh” [12-14]. Gram pod borer *H. armigera* emerges as a formidable and pervasive agricultural pest that has garnered global attention for its destructive impact on a wide array of crops in agro ecosystem. This insect species belongs to the family Noctuidae and is characterized by its polyphagous nature, feeding on an extensive host range, 182 host species of crop plants are attacked by *H. armigera* [15]. Some reports show that 47 species of host plants are attacked by the same pest [16]. Its ability to afflict such diverse crops has earned it the reputation of a key pest in agriculture, contributing to substantial economic losses and posing a constant challenge for farmers across continents. Native to the Old World, *H. armigera* has undergone a remarkable expansion of its geographical range, facilitated by globalization, international trade and climate change. What was once predominantly an Old World pest has now become a global concern, adapting to various environmental conditions and establishing a pervasive presence in regions ranging from Asia and Africa to Europe and other countries. The adaptability of this pest is underscored by its capacity to exploit a multitude of crops and successfully navigate different ecosystems, making it a resilient and elusive target for pest management efforts. One of the distinctive features that adds to the complexity of dealing with *H. armigera* is its polyphagy—the ability to feed on a diverse range of plant species. This adaptability not only makes it challenging to predict its presence and impact on specific crops but also complicates the implementation of targeted control strategies. Furthermore, the pest's biology and behavior are influenced by a variety of factors, including climate, host plant availability and agricultural practices, making its management a multifaceted puzzle. In addition to its broad host range, *H. armigera* exhibits a remarkable capacity for developing resistance to insecticides [17]. This adaptability poses a serious threat to conventional pest control methods, necessitating a constant evolution in agricultural practices to keep pace with the pest's ability to overcome chemical defenses. The development of resistance not only reduces the efficacy of chemical pesticides but also underscores the importance of integrated pest management (IPM) approaches that encompass a variety of strategies to mitigate the impact of this resilient pest. "Integrated pest management strategies have been emphasized by several researchers to minimize the pest populations which include use of resistant cultivars, adoption of recommended cultural practices and use of biological and chemical control measures" [4]. "Uses of pod borer resistant cultivars guarantee a pest free crop and incur almost no further charge to chickpea growers" [18]. Understanding the biology, ecology and genetics of *H. armigera* is crucial for unraveling the complexities associated with its pervasive presence in agriculture. Scientific research plays a pivotal role in exploring the mechanisms underlying its adaptability, resistance development and reproductive strategies. By delving into the intricacies of its life cycle, mating behavior and genetic makeup, researchers can identify vulnerabilities that may be exploited for effective pest control. As global agricultural systems strive to address the challenges posed by *H. armigera*, there is a pressing need for collaborative research efforts, innovative technologies and sustainable pest management practices. Unraveling the complexities of this pervasive agricultural pest requires a multidisciplinary approach that integrates entomology, genetics, ecology and agronomy. Only through a comprehensive understanding of *H. armigera* we can hope to develop strategies that safeguard crops, enhance food security and promote sustainable agriculture in the face of this relentless and adaptable adversary.

2. DISTRIBUTION

Gram pod borer, *H. armigera* exhibits a widespread distribution with a global impact on agriculture originating in the Old World; the native range of *H. armigera* encompasses regions in Africa, Asia, Europe and the Middle East. However, the species has significantly expanded its reach, becoming a notable agricultural pest in various continents. It is widely distributed in Asia, Africa, the Mediterranean region and Oceania [8], causing damage to a diverse array of crops. "Outbreaks of *H. armigera* were reported in Hungary, Italy, Romania, Slovakia, Spain, Sweden, Switzerland and the UK. *H. armigera* is established as a widespread pest in Bulgaria, Greece, Portugal, Romania and Spain, with restricted distribution in Cyprus, France, Hungary and Italy. Substantial yield losses due to this pest have been reported across South Asia. In India, 10–85 per cent yield losses have been documented in chickpea" [12, 19-22]. "In Bangladesh and Nepal, pod borer damage in unprotected chickpea fields has been in the range of 5–15 per cent" [23]. "In northern Pakistan, up to 90 per cent pod damage due to *H. armigera* has been recorded in unprotected chickpea fields. Crop rotation with a similar host crop, introduction of new varieties, land reclamation, pest migration and the use of irrigation and fertilizer have contributed to the increase populations of polyphagous insect-pests such as *H. armigera"* [24- 27,]. The adaptability and resistance of *H. armigera* to certain pesticides pose challenges for farmers in the region. *H. armigera* has established itself as a significant agricultural pest, known for damage to many crops the *H. armigera* presence underscores the need for international collaboration and coordinated pest management efforts to address its impact on global agriculture. Monitoring its distribution, understanding its ecology and implementing sustainable control strategies are essential components of managing the challenges posed by *H armigera* on a global scale.

3. LIFE CYCLE AND DEVELOPMENT

The life cycle and development of *H. armigera*, commonly known as the Gram pod borer, are intricate processes marked by distinct stages, each playing a crucial role in the pest's reproductive success and population dynamics. *H. armigera* completes its life cycle, from egg to adult in 4-5 weeks at an average temperature of 28°C [28, 11, 5]. The life cycle of this insect comprises four main stages: egg, larva, pupa and adult. Moths, characterized by robust bodies and broad thoraxes, represent the adult stage. A single female can lay 3,000 to 4,400 eggs under laboratory conditions, but the average in the field is closer to 500 to 1,000typically on leaves, pods, or flowers [29, 30]. The oviposition period spans 5-24 days and the incubation of eggs takes 3-5 days, influenced by temperature and host plant preferences. The selection of host plants is affected by environmental conditions and the availability of suitable crops plays a role. Freshly laid eggs exhibit a yellowish-white hue, which transforms into a dark brown shade just before hatching [31]. Upon hatching, the larvae emerge and go through six distinct instars, representing caterpillar stages 1-6. Initially, these larvae consume leaves, young twigs and flowers. However, as they progress through later stages, they infiltrate developing pods by creating openings at the base of the pod [32]. The pre-pupal stage spans a duration of 1-4 days. Typically, the pupal phase lasts from 10 to 16 days, with pupation commonly taking place in the soil or within a safeguarding cocoon. However, the exact duration is temperature-dependent, ranging from 6 days at 35°C to as long as 30 days at 15°C. In extremely low temperatures (winter) and high temperatures (summer), the insect undergoes facultative diapause as an adaptive strategy to survive unfavorable environmental conditions [33, 34]. "The winter diapause is induced by exposure of the larvae to short photoperiods and low temperatures. Pupae exposed to exceeding 30°C temperatures produce pale colored adults" [11]. "Male and female adults have distinguished color pattern showing greenish grey and orange brown respectively. The female moths generally live longer than male" [35]. Adult moths are equipped with specialized mouthparts for feeding on nectar, but their primary focus is reproduction. *H. armigera* are capable of traveling long distances in search of suitable host plants for oviposition. The entire life cycle, from egg to adult, is influenced by environmental conditions such as temperature, humidity and host plant availability. All of these life history features contribute to make *H. armigera* one of the 'world's worst pest' [36]. *H. armigera* has the ability to complete multiple generations in a single growing season, contributing to its status as a pervasive agricultural pest. Additionally, the adaptability of this pest to various crops and its rapid development of resistance to insecticides further complicate efforts to manage its population effectively. The intricate interplay of these stages underscores the challenges in controlling this polyphagous pest and emphasizes the importance of integrated pest management strategies that consider the various phases of its life cycle.

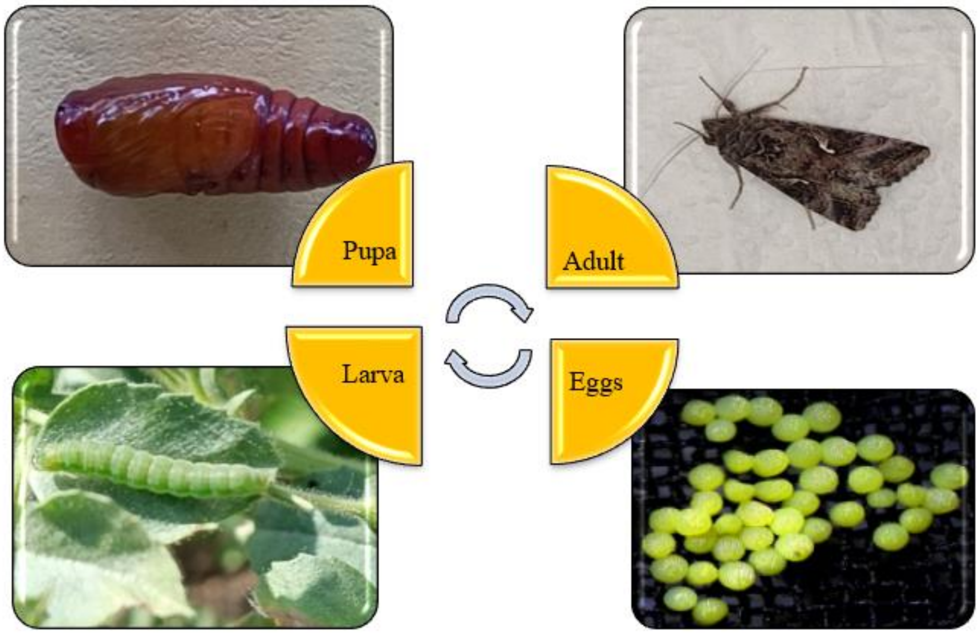

Fig. 1. Life cycle of Gram pod borer, *Helicoverpa armigera*

3.1 Host Range

H. armigera, a polyphagous insect, feeds on a diverse array of plants from families such as Asteraceae, Fabaceae, Malvaceae, Poaceae and Solanaceae [37]. Pod borer can survive on several host species of crop plants. *H. armigera* feeds on 182 host species of crop plants [15, 37, 38] and some workers have reported that 47 species of host plants are attacked by it [16]. “The most important host crops of *H. armigera* are tomato, cotton, pigeon pea, chickpea, sorghum, and cowpea. Other hosts include dianthus, 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 and flower crops” [39-43]. “The maize, chickpea, sorghum, pigeon pea, okra, tomato and several other crops as preferred host crops for survival of *H. armigera”* [44]. “Out breaks of pod borer have been observed on chickpea crop due to cultivation of cotton, pigeon pea, maize, tomato, sorghum, cowpeas and okra crops in surroundings because of shift of pest populations to chickpea crop”[12,11]. “Rotation of common host crops has contributed to lift up the polyphagous insect pest populations like chickpea pod borer” [24]. “Irrigation strategies generate new habitats promoting the migration process of some species of pests to the areas that were otherwise away from reach and the insect populations generally develop and migrate to that area” [45]. Laboratory studies on host preference indicate that corn, sorghum, chickpea and tobacco are the most preferred for oviposition followed by various cotton varieties, whereas cowpea and alfalfa are the least favored. Cotton and corn are found to be more conducive to the development and reproduction of the cotton bollworm compared to peanut [46]. Pigeon pea and corn are considered the most suitable hosts, surpassing sorghum, red ambadi, marigold and artificial diet [47]. In another study, tobacco, corn and sunflower are identified as the most preferred hosts, while soybean, cotton and alfalfa are intermediate hosts. Cabbage, pigweed and linseed are categorized as the least preferred hosts by *H. armigera* [48].

3.2 Nature of Damage

“H. armigera, gram pod borer or chickpea pod borer, is a notorious insect pest that poses a significant threat to chickpea crops. This polyphagous pest is highly adaptable and has a wide range of host plants, making it a challenging adversary for farmers cultivating chickpeas. The 1st,2nd and 3rd instar larvae initially feed on the foliage of chickpeas and a few other legumes, but mostly on the flowers and flower buds of chickpea, pigeon pea, etc. Larvae shift from foliar feeders to developing seeds and fruits as larval instar development progresses” [49]. The young chickpea seedlings may be destroyed completely, particularly under tropical climates in southern India. Larger larvae bore into pods and consume the developing seeds inside the pod. The pod borer attacks crops from seedling to maturity, damaging all parts of the plant (leaves, flowers, and pods). Initially, the larvae feed on the leaves and tender twigs of the chickpea plant causing defoliation. This defoliation weakens the plants, making them more susceptible to environmental stressors and other pests and later, when the pods are developed, the larvae bore into the chickpea pods, consuming seeds and rendering them unfit for harvest resulting in low yield. The damage caused by *H. armigera* in chickpea cultivation encompasses not only direct yield losses but also compromises the quality of the harvested produce. Sustainable and integrated pest management practices are imperative to mitigate the impact of this versatile pest and safeguard chickpea crops from economic losses.

3.3 Management Strategies for *Helicoverpa armigera*, Gram Pod Borer

Effectively managing *H. armigera* is crucial for achieving sustainable chickpea yields. Numerous researchers have underscored the significance of integrated pest management (IPM) strategies to minimize pest populations. These strategies encompass the use of resistant cultivars, adherence to recommended cultural practices and the application of biological and chemical control measures [50]. The adoption of pod borer-resistant cultivars ensures a crop free from pests and involves minimal additional costs for chickpea growers [18]. Additionally, implementing practices such as early sowing of chickpea crops, maintaining optimal plant density, installing perches for insectivorous birds and intercropping with trap crops proves beneficial in pest management. Researchers are extensively employing various natural pathogens, insect parasitoids, predators and plant materials for the biological management of pod borers [45]. In situations of insect pest outbreaks, when all else fails, farmers resort to insecticides as a last option. Various insecticide groups, including pyrethroids, hydrocarbons, carbamates and organophosphates, have been introduced for the chemical control of pod borers [51].

Key component of management is the implementation of chemical control, varietal resistance, adoption of recommended cultural practices and use of bio-control agents and integrated pest management strategies.

3.4 Breeding Varietal Resistance

Utilizing varietal resistance is a crucial strategy for effectively managing *H. armigera*, a common pest in chickpea cultivation. By selecting and cultivating chickpea varieties that demonstrate resistance to this particular pest, farmers can significantly mitigate the impact of *H. armigera* on their crops. Several characteristics antixenosis, pod thickness, length, density and pods plant significantly contribute towards resistance against chickpea pod borer [52,18]. This resistance not only reduces the susceptibility of chickpea plants to pest infestations but also contributes to sustainable and environmentally friendly agricultural practices. Trichome types, length, density and orientation are associated with reduced pod damage. The association among pod borer damage and pod wall thickness exhibit negative correlation therefore genotypes having more wall thickness are generally less damaged. Similarly, pod length, area and breadth have also a considerable effect on pod borer resistance showing a negative association among the extent of damage, pod length and area. However, positive associations among pod borer damage and the pods plant have been reported [53, 54]. Development and utilization of pod borer resistant cultivars serves as the most efficient and sustainable control method for chickpea pod borer. Utilization of resistant varieties is most effective method and incurs no extra charge to the growers. Hence, the breeding objective must be to identify and utilize the genetic resistance sources to chickpea pod borer. Development of genetically advanced varieties having improved pod borer resistance is feasible provided that a good source of resistance is available. The selection procedures like mass selection, bulk and pedigree selection approaches can be utilized for the development of chickpea pod borer resistant varieties. Recurrent selection procedure has been found more efficient to accumulate the desired alleles in a single genotype and to break the undesired blocks [55, 56]. These schemes require characterization of large populations, repeated selections and inter crossing among selected parents. Mutation breeding can also be utilized for creation genetic variation in performance of various traits having positive influence on resistance for pod borer damage. Several studies on genetic resistance and use of molecular markers were conducted by different researchers to identify the tolerant and resistant sources. Varied resistance mechanisms in these selected chickpea varieties serve as a proactive approach to pest management, offering a promising solution for enhancing crop yields and ensuring the overall health and productivity of chickpea crops in the face of *H.armigera* challenges.

3.5 Agronomic Recommended Practices

3.5.1 Sowing time

Growth and yield of chickpeas are notably impacted by the timing of planting. Several environmental elements, such as humidity, temperature, duration of sunlight, and wind speed, play a pivotal role in influencing the populations of gram pod borer [57], there is a positive correlation between temperature and the population of gram pod borer larvae, while rainfall and relative humidity have a reducing effect on larval populations. Late-sown crops are generally more susceptible to gram pod borer infestation compared to early-sown crops [58]. The direct correlation between yield and pod damage in delayed sowing with less grain yield observed [59]. The larval population of pod borer is lower and minimum percentage of pod damage was observed in early-sown crops [60]. In the context of Pakistan and Indian conditions it was reported that crops sown in October-November typically experience the least impact compared to those sown later [11]. Early instars usually emerge in early April, remaining confined to leaves for sustenance. However, the later instars, responsible for significant pod damage, typically appear in late April when the pods are fully developed and mature. During this period, limited damage can occur and early-sown chickpea crops tend to avoid this critical phase.

3.5.2 Plant density in field

The level of pod damage in chickpea crops is influenced by plant density and planting geometry [61]. A higher plant density contributes to increased pod damage. It was found that the denser crops tend to host higher larval populations, leading to a subsequent loss in yield

[62]. In situations where chickpea growers face challenges such as unfavorable soil conditions and unreliable seed germination, thinning is suggested as a potential solution to reduce plant density. This recommendation arises from the understanding that some growers may have limited options to adjust seed rates effectively.

3.5.3 Use of trap crops

Trap cropping is an agronomic strategy employed to divert or confine insect pests away from primary commercial crops. This method involves the cultivation of specific crops, referred to as trap crops, either to prevent insects from entering the main crop or to capture them in an alternative crop located away from the primary cultivation. The selection of trap crops is contingent upon the target pest species and the developmental stage of the main crop. Certain plants emit chemical compounds that attract insects for pollination purposes, rendering them suitable candidates for trap crops. Diverse crop species produce varying levels of volatile compounds, selectively attracting specific insect species, thus making them conducive to trap cropping [44,63]. Concentrating the insect population in trap crops facilitates efficient pest management, enabling the application of targeted treatment measures in specific areas, mitigating the need for widespread crop treatment. This targeted approach is both cost-effective and highly efficacious in controlling insect populations. Several crops, including maize, sunflower, sorghum, safflower, pigeon pea, okra and tomato, have been identified as suitable host crops for trap cropping. These crops can be strategically planted on field borders or interspersed in rows, maintaining a ratio of 10:3 (Chickpea: Trap crop rows, respectively) throughout the field. A study incorporating sunflower and marigold as trap crops in a ratio of 7:1 demonstrated a significant reduction of 34-40 per cent in pod damage. This underscores the potential of trap cropping as a practical and effective approach in integrated pest management strategies.

3.5.4 Nutrient management

Fertilizers are primarily applied to produce high yield of a crop, but the application of nutrients to crop results direct effect on pest attacks [64]. Increased application of NPK (nitrogen, phosphorus and potassium) enhances the plant growth which becomes more attractive to chickpea pod borer. The bushy plant types provide better refuge for insects, resulting in more pod damage while low doses of NPK resulted in less pod damage [65]. Similarly, the increase in phosphorous levels significantly minimized insect incidence and increased the chickpea seed production [62]. The applications of fertilizer change the plant physiology and makes it active host for pod borer. Application of inorganic fertilizers to chickpea crop showed maximum pest population in comparison to the organic manures. There is the impact of fertilizers on pod borer populations and found that nitrogenous fertilizers specifically contribute to pod damage [66]. Consequently, it is suggested to consider reduced doses of NPK to manage and control the pod borer population.

3.5.5 Intercropping system

Intercropping in traditional farming systems serves as a form of insurance against pests and unpredictable weather conditions, offering several advantages over sole cropping. By altering crop geometry and the overall cropping system, it creates opportunities for ecological manipulation of faunal populations, potentially impacting pest-related economic losses. Intercropping chickpea with certain crops has been shown to reduce damage from pod borer. This may be a result of the companion crop harboring higher numbers of natural enemies or non-preference for egg laying by pod borer in a field containing the intercrop. By concealing a plant among other species, which do not offer the same kind of stimuli, it should be possible to reduce the efficiency of the pest's host seeking behavior and to interfere with its population development and survival [36]. Intercropping chickpea with linseed, wheat and mustard, as well as other non-host crops, has been reported to significantly lower the pod damage compared to chickpea sole crops [20, 67, 68]. Similarly, pod borer damage was reduced by 38.3 per cent in chickpea + wheat mixed cropping as compared to chickpea sole cropping. Intercropping generally delayed the appearance of major chickpea pests and reduced their incidence, particularly the linseed intercrop [69-71]. The minimum larval population and the highest chickpea grain yield were found in chickpea + mustard, followed by chickpea + barley and chickpea + wheat [72]. Similar results have also been supported by other workers [73-75]. According to research findings, chickpea intercropped with coriander, known for its nectar-rich properties, promoted parasitoid activity and resulted in minimal *Helicoverpa* population, reducing pod borer incidence [76-80]. Additionally, intercropping with safflower and sunflower contributed to reduce pod damage by distributing larvae between chickpea and the intercrop during chickpea pod development stages [81,82].The practice of intercropping chickpeas with certain crops has demonstrated a reduction in pod borer damage. This outcome may be attributed to the companion crops providing a habitat for increased numbers of natural enemies or deterring pod borer egg laying. The strategic concealment of plants among other species disrupts the pest's host-seeking behavior, interfering with population development and survival.

3.5.6 Bird perches

Several species of insect-eating birds have been identified as effective predators of crop-damaging pests, such as the pod borer, with documented cases indicating an impressive reduction of up to 84 per cent in larval populations in Punjab, India [83]. Noteworthy among these predatory birds are the black drongo, house sparrows, blue jays, cattle egret, rosy pastor and mynah, which are known to prey on significant numbers of *H. armigera* and other lepidopteran insects affecting chickpea, pigeon pea and groundnut crops [84]. Despite the world's diverse avian population, the valuable contribution of insectivorous birds to pest management has been largely overlooked, primarily due to the prevalent use of broad-spectrum insecticides in plant protection practices [85-88]. Consequently, there is an urgent need to prioritize and implement eco-friendly approaches for managing chickpea pod borers to ensure sustainable production.

3.6 Biological Control

Biological agents present a sustainable and economically feasible alternative to chemical methods for managing chickpea pod borer. Biological control is a bioeffector approach that utilizes living organisms, including plants, animals, bacteria, entomopathogenic nematodes and virus-based products, to combat pests. This method depends on natural mechanisms such as predation, parasitism and herbivory, with human intervention playing an active role in management.

Extracts from plants and animals are considered safer and more cost-effective than chemical insecticides [89]. The most well-known and commonly used plant extract is Azadirachtin, isolated from the seed, wood, bark, leaves and fruits of the neem tree (*Azadirachta indica*). Azadirachtin has both antifeedent and growth-retarding properties and can lead to death at any stage in the life cycle, probably by interfering with the neuroendocrine control of metamorphosis in insects [90]. Neem and garlic extract have larvicidal, toxic, repellent, ovicidal, antifeedent and antioviposition effects on insect-pests [91-93]. Applying Neem Seed Kernel Extract (NSKE 5%) treatment reduced the pod borer population in chickpea [94-96]. Leaf, bark and seed extract from *Annona squamosa* have pesticidal and insect antifeedent properties [97-99]. Applying a potent plant pesticide with vermiwash is the best alternative to chemical fertilizer and pesticides. In India significant decrease in the percentage of pod damage after spraying vermiwash with neem oil and custard apple leaf extract [100]. The vermiwash, combining animal dung and municipal solid wastes with aqueous garlic extract, caused the maximum percentage of reduction in the pod borer infestation rate. The vermiwash obtained from buffalo dung and municipal solid wastes with neem oil and garlic extract were more effective for better plant growth, productivity and management of the pod borer infestation rate.

In the realm of pod borer control, virus and bacteria-based insecticides have proven to be highly effective. The efficacy of species-specific nuclear polyhedrosis viruses (NPVs) in significantly reducing chickpea pod borer infestations [5]. The NPVs led to a remarkable 78 per cent reduction in pod damage, surpassing the 70 per cent achieved with the chemical insecticide Endosulfan. Many other workers have reported significant reductions in pod borer larval population and accordingly less pod damage in chickpea from NPV application, as compared to chemical insecticides and control measures [101-113].

Additionally entomopathogenic nematodes (EPNs) have emerged as effective biological control agents against the notorious pest *H. armigera* in chickpea cultivation [114]. EPNs belonging to genera *Steinernema* and *Heterorhabditis*, exhibit a remarkable ability to seek out and infect their target pests, including *H. armigera* larvae. Once applied to the soil, EPNs actively hunt for their prey, entering the larval stage of the pest through natural openings or by penetrating the body wall. Inside the host, EPNs release symbiotic bacteria that rapidly multiply, causing septicemia and ultimately killing the pest [115,116]. This biological control method offers several advantages over chemical pesticides, including its specificity to the target pest, minimal impact on non-target organisms and reduced environmental contamination. EPNs are compatible with integrated pest management strategies, making them a valuable tool for sustainable pest control in chickpea cultivation. Research and field trials have demonstrated the efficacy of EPNs in suppressing *H. armigera* populations, leading to improved yield and quality of chickpea crops while reducing reliance on synthetic chemicals. As such, the integration of entomopathogenic nematodes into chickpea pest management programmes holds promise for enhancing agricultural sustainability and resilience.

Furthermore, bacterial insecticides have emerged as both environmentally friendly and potent agents against chickpea pod borers. The detrimental effects of chemical insecticides on the environment, soil and wildlife, while microbial insecticides, with no residual effects, are recognized as eco-friendly alternatives. In the developed world, use of *Bacillus thuringiensis* (Bt)-based microbial insecticide preparations provides an eco-friendly alternative to the generally hazardous broad-spectrum chemical insecticides The efficacy of Bt can be enhanced by incorporating suitable quantities of acids, salts, oils, adjuvants, thuringiensis (exotoxin of Bt), and chemical insecticides [117-123]. Applying DiPel 2X and DiPel ES at 1.6 and 1.5 l ha^{-1}, respectively, at early stages of crop infestation (1st, 2nd, and 3rd instar larval infestation) with at least two applications at 7-day intervals resulted in increased chickpea yield [124,125]. Preparations of Bt-based insecticides, with BioBit, Delfin and DiPel together with NPV showed minimum pod damage [126]. It appears that Bt-based insecticides can act as effective IPM tools if awareness is developed among farmers about the critical time and method for their safe application. Bacteria-based (Bt) insecticides, particularly in combination with NPV, have proven to be a superior integrated pest management (IPM) tool for pod borer control. The utilization of Bt-based insecticides, such as DiPel, Delfin and BioBit, in conjunction with NPV, resulted in the most efficient reduction of pod damage [97].

3.7 Chemical Control

In response to outbreaks of *H. armigera* infestations farmers often resort to insecticides as a last resort for pest management. Several researchers have conducted thorough investigations to assess the efficacy of specific insecticides and provide recommendations for the effective control of gram pod borer, *H. armigera*. The impact of various insecticides, including Chlorpyrifos, Endosulfan, Indoxicarb, Profenofos and Spinosad as well as an untreated control, against gram pod borer [127]. Their findings indicated that Indoxicarb and Spinosad demonstrated the highest effectiveness, resulting in a significant reduction of pod borer infestation in chickpea crops. Further investigated that the efficacy of diverse insecticides in managing chickpea pod borer, [128] identifying Spinosad as the most useful, followed by Indoxacarb. Similarly, other insecticides, such as Cyperthrine 10% EC, Deltamethrin 2.8% EC, Emamectin Benzoate 5% SC, Endosulfan 35% EC, Flubendiamide 480% EC, Fenvalenrate 20% EC, Indoxicarb 15% EC, Lambda Cyhalothrin 5% EC, Quinalphos 25% EC, Thiacloprid 240% SC and Spinosad 45%, have demonstrated efficacy in controlling *H. armigera* in various research studies [129]. The scientific literature highlights the importance of judicious insecticide selection for chickpea pod borer management. The research consistently underscores the effectiveness of specific insecticides, such as Indoxicarb, Spinosad and others, in significantly reducing the impact of pod borer infestations, providing valuable insights for farmers seeking sustainable pest control strategies in chickpea cultivation.

3.8 Integrated Management Practices

H. armigera, commonly known as the chickpea pod borer, poses a significant threat to chickpea crops worldwide, necessitating the implementation of integrated management practices to mitigate its impact. A comprehensive approach that synergistically combines cultural, biological and chemical control strategies is imperative for effective *H. armigera* management in chickpea cultivation. Cultural practices involve the manipulation of agronomic factors to create an unfavorable environment for the pest. This includes adopting suitable planting dates, crop rotation and intercropping with pest-resistant varieties. The biological control methods, such as the release of natural predators and parasitoids, play a pivotal role in regulating *H. armigera* populations [130]. Furthermore, judicious and targeted use of chemical control, involving the application of insecticides, forms an integral component of integrated management. However, emphasis should be placed on the selection of environmentally friendly and pest-specific formulations to minimize collateral damage to non-target organisms. The integration of these practices demands a precise understanding of the pest's life cycle and behavior, enabling the implementation of timely interventions. Regular monitoring and surveillance are essential components, facilitating the early detection of infestations and the prompt application of control measures. The amalgamation of these integrated management practices not only ensures sustainable chickpea production but also contributes to the broader goal of pest management with ecological prudence.

4. CONCLUSION

Achieving sustainability in chickpea cultivation necessitates an integrated management strategy for pod borer, encompassing the harmonious implementation of various measures and practices. This holistic approach includes the development and cultivation of chickpea varieties resistant to pod borer, the adoption of sound agronomic practices, habitat manipulation and the incorporation of biological control methods. Culturally, the optimization of chickpea yield and sustainable pod borer management involves early sowing of resistant or tolerant varieties at appropriate planting densities and fertilizer levels as well as the cultivation of inter/trap crops such as coriander, mustard, linseed, sunflower, sorghum and marigold. Additionally, the installation of animated bird perches, such as those utilizing sunflower and sorghum, along with T-perches positioned at 2-meter intervals in chickpea fields proves beneficial. It is emphasized that relying solely on a singular pest control method may prove impractical. Therefore, the preferred approach is Integrated Pest Management (IPM), which centers on pest management rather than complete eradication. The synthesis of IPM options, coupled with the cultivation of resistant varieties, adherence to optimal agronomic practices, utilization of biological control agents, judicious chemical control when necessary and the incorporation of behavioral approaches, collectively mitigates the adverse effects of insecticides on natural enemies within the ecological niche. This comprehensive strategy serves to safeguard the ecosystem and the environment from potential toxicological hazards. The present review underscores the efficacy of an integrative and ecologically sensitive approach to chickpea cultivation for sustainable gram pod borer management.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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